INVESTIGATIONS INTO CHEMISTRY MISCONCEPTIONS OF HIGH SCHOOL STUDENTS

by

Ethan C. Dusto

B.A., Cornell University, 2004

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This thesis for the Masters of Science

degree by

Ethan C. Dusto

Has been approved by

[redacted]

Doris Kimbrough, Chair

[redacted]

Mark Anderson

[redacted]

Hai Lin

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Dusto, Ethan C. (M.S., Chemistry)

Investigations into Chemistry Misconceptions of High School Students

Thesis directed by Associate Professor Doris Kimbrough

ABSTRACT

Students have varying degrees of misconceptions relating to the field of chemistry which arise from a number of different sources. Survey based pretests were given to a group of high school students and a posttest was generated from their responses. The posttest was then given as a pre- and posttest to a second group of students the following year. The results were analyzed to see what misconceptions persisted with students from the pretest to the posttest. The misconceptions that each distractor represented were then explained. The data suggests that students all made gains from the pretest to the posttest to varying degrees.

This abstract accurately represents the content of the candidate's thesis. I recommend its publication.

Signed [redacted]

Doris Kimbrough

This thesis is dedicated to

my parents who have always

supported me in everything that

I have done and to Kate who

stood by me throughout

this entire process; I could not

have done this without your help.

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CHAPTER I

INTRODUCTION

The process of understanding and learning science is very rigorous for high school students, especially in the field of chemistry. Each new topic that they learn needs to be based on the previous knowledge that they have gained. Unfortunately, much of their previous knowledge is flawed, coming from misconceptions that have been developed through a number of different sources[1]. These misconceptions arise from personal experiences that students have had with the physical world, the influence of media, interaction with other individuals, and from faulty instruction[2]. These misconceptions vary from a slight deviation from accepted scientific explanations to those that have no grounding in modern science. Many of these misconceptions are present both before and after the teaching process has taken place[3]. The ideas that students bring into their science courses influences how they will learn new knowledge in science[4]. Science educators have the unique problem of trying to explain a concept in a way that is scientifically accurate but also that uses terminology that is accessible by students so that they are capable of understanding the topic.

For the purposes of this study, we are defining a student with a misconception as a student who possesses an understanding that is either incomplete or inaccurate when compared to how that topic is understood by the scientific community[5]. For example, when students were asked to account for the loss in mass of a match through a combustion process, many were able to cite concepts such as the law of conservation of mass or the law of conservation of energy, but they could not apply them correctly. Many students instead responded that the mass lost through the process was converted to energy as evidenced by the light and heat given off through the process. This is a misconception because the scientific

community cites the production of a gas (carbon dioxide) as the major component of the mass "lost" by the match.

This study attempts to identify some of these misconceptions as they relate to the field of chemistry. Through open ended pretest assessment, a standardized test was generated, following the psychometric method to use exams that are driven by student misunderstandings of topics[6]. In this way the test can be used as a tool for teachers of high school chemistry to help to identify specific chemistry misconceptions and address them throughout the school year in order to rid students of these false ideas[7].

CHAPTER II

METHODS

As previously mentioned, the research was based on pre- and posttest analysis. The initial pretests given were a series of open ended questions, administered at the beginning of every unit. Pretest questions were generated through teacher experience and questions previously raised by other researchers[5,6,10,11,12,13]. Each test had between five and ten questions of varying difficulty. The students were given ten to twenty minutes on each survey. Example surveys are included in the appendix.

All students tested were enrolled in the Honors Chemistry course at Cherry Creek High School in Englewood, Colorado. Englewood is an affluent suburb of Denver and Cherry Creek HS is consistently rated as a top high school in the state of Colorado. The Honors Chemistry course itself is designed for honors level sophomores and juniors. Sophomores have had physical science as their previous course. The physical science course is designed as a survey of physics, chemistry, and earth science. Juniors enrolled in the course have also had regular level biology in addition to physical science[8].

Every student was administered the surveys, but only surveys of students who had turned in permission waivers were analyzed for the purposes of this process. All students were given a permission waiver which was explained, verbally, to parents at "back-to-school" night. Obtaining the waivers and administering the surveys were in compliance with traditional COMIRB protocols.

The results of these pretests were analyzed and the four most popular student responses that reflected misconceptions along with the correct answer were translated into multiple choice answers. The forty most relevant questions were used to create a posttest that could be administered during a fifty minute class period. Each question was presented as a multiple choice question with a prompt or stem (the question itself), followed by two to five answer choices. Only one of the choices was correct, and its

wording of was a combination of student vernacular as well as generally accepted explanations. The other choices were incorrect answers, or distractors, that were generated from common student responses. The distractors on the posttest represent an aggregate of what students replied on their pretests, slightly modified to apply to a multiple choice format.

This posttest was then given as a pretest to a second set of students (the following year) as well as a posttest to analyze the effectiveness of the test and the teaching methods implemented. Students were presented with auditory and visual instruction on the subject material as well as practical "hands on" examples through laboratory experiments. In some cases, the misconception scenarios presented in the test were addressed specifically, stating the misconception, why it is wrong, and what the more accepted interpretation of the concept would be. The test itself was reviewed by seven other high school chemistry teachers for correctness, wording, and relevance to the course itself.

As the surveys were administered to live test subjects who were also minors, many steps were taken to insure that the subjects' rights were protected. The testing protocol and each individual survey and posttest were submitted to the Colorado Multiple Institutional Review Board for approval. This is an extensive process by which the principle investigator is first administered an exam proving his knowledge on the rights of different individuals, including the general public, inmates at mental and correctional facilities, pregnant women, mentally and physically handicapped individuals, and minors[9]. Once this knowledge was proven, the protocol was submitted for initial board approval.

After approval was granted, the school board, school principal, school director of research, parents of the students involved, and student test subjects were all notified and all required to grant permission in order to proceed. All permission approvals were stored in a secure facility at all times. Student and parent permission waivers were stored at a separate secure facility. All analyzed test results were kept anonymous and all name identifiers were removed. Because the results were aggregated, no

student identifier was necessary, furthering the anonymity. No student was individually tracked through this process.

Once the posttest was generated from student responses, it was submitted for approval as well. The process was repeated for the second year of students. For these students, the posttest was administered after all the information was covered, not at the end of the school year (as was done for the first year of students). All pre- and posttest results were then entered into a Microsoft Excel spreadsheet for analysis.

Each question was entered as a row of data, and the number of students who selected the choice was entered in the following columns. This value was divided by the total number of students who answered that question and then multiple by 100 to generate a percent (rounded to the ones place for significance). All calculations were performed using formula functions of Microsoft Excel.

CHAPTER III

RESULTS

Pretest survey results have been broken down by survey

Answer is followed by the number of students who selected that answer. Correct Answer is highlighted. Surveys are present in the appendix.

Table 3.1, Atoms and Molecules Pretest Results

Question 1		**Question 2 part1**	**part2**		**Question 3**		**Question 4**		**Question 5**
No Answer/Nonsense		No Answer/Nonsense	No Answer/Nonsense		No Answer/Nonsense		No Answer/Nonsense		No Answer/Nonsense
13		1	4		9				
One atom		Salt in container (no water)	Mass decreased (no water)		Molecules breaking apart		**Pure**		true
8		20	18		9		85		51
Six		**Salt and water vapor**	Mass down (gas less dense)		Molecules further apart		Impure		**False**
1		85	14		22		22		56
Many		Salt and oxygen	**Stay same**		**Individual molecules splitting apart**				
52		1	63		28				
Can't tell w/o penny mass			Mass increases (heat gain)		Molecules speed up				
13			1		20				
twenty nine			Mass increases (salt more dense)		Gaining energy				
4			1		7				
1.24E+16			Small change		Rising				
1			5		2				
Can't tell w/o penny volume					Vibrate faster				
3					3				
1 billion					Decreasing				
4					1				
10 billion					Nothing				
2					1				
Trillions					Heating				
1					2				

Table 3.2, Stoichiometry Pretest Results

Question 1	Question 2	Question 3	Question 4	Question 5
No Answer/Nonsense	No Answer/Nonsense	No Answer/Nonsense	No Answer/Nonsense	No Answer/Nonsense
3	2	5	6	4
Yes, 1:1	Yes, 1:1	Yes, 1:1	Mass to energy	Mass down (chem reaction)
39	51	10	35	1
Yes, balances to 2	Yes (charges)	No (can't compare)	Mass to Co2	Mass same (law of conservation)
2	1	2	13	21
Yes, no explanation	No (nonsense)	No (need 1 mole)	Mass to reaction	Mass up (rust adds weight)
68	14	16	19	21
No, different atomic mass	Yes (nonsense)	Yes, no explanation	Mass to gas	Mass up (oxygen added)
12	7	10	61	33
No, leftover hydrogen	No (1 molecule only)	No (not enough)	Mass to carbon	Mass down (rust removes weight)
3	48	14	6	19
No, 1:1	Yes (slowly)	Yes (slowly)		Mass up (extra matter)
4	4	3	reaction not necessarily	16
No, small leftovers	Unlikely (no collision)	Yes, amt doesn't matter	a gas or co2	Mass up (no explanation)
1	7	46		1
No, no explanation	No, no explanation	Yes, if amts/ratio equal		Mass same (no change to chem form)
3	1	16		14
		Yes (nonsense)		Mass down (gas release)
		2		2
		No, not 1:1		Mass same (no explanation)
		6		3
		Yes, w/ leftovers		
		4		
		No, no activation energy		
		1		

Table 3.3, Atomic Structure Pretest Results

Question 1		**Question 2**		**Question 3**		**Question 4**		**Question 5**		**Questior**
Attractions	14	Oscillations	8	Nonsense/Nothing	36	Nonsense/Nothing	41	Nonsense/Nothing	18	Nonsens
Empty space	66	Massless	8	Not accurate	17	Quantities/Packets	59	Electron's path	37	Don't kn electron
Electron clouds	13	Nonsense/Nothing	39	Electrons don't have locale	30	Measured in terms of light	3	Where electrons are	36	Chance t anywher
Protons/neutrons	9	Have frequency	55	Doesn't explain light	2	Waves turn into mass	2	Electron clouds	12	People m mistakes
Nonsense/nothing	12	Releasing energy	1	No electrons	9	Energy is transferred	6	Circular path	10	Average
Gas	3	Energy levels	3	All electrons in 1 orbital	5	to be contained	6	Gravitational pull	1	Don't kn atom loo
Plasma	1	Visible	1	No protons	2	Measured in relation	1	Configuration	2	Electrons have set
Bonds	4	Moves at speed of light	9	No valence electrons	2	Energy is saved	1	Energy level	6	Things ar different
Energy	5	Continuous	4	2-d only	9	Different levels	4	Nucleus path	1	Not all at same
				Electrons close together	1	Bigger	1			
				Electrons don't move	3	Has mass	1			
				Works for H only	6					
				No nucleus	3					

Table 3.4, Molecular Bonding Pretest Results

Question 1		**Question 2**		**Question 3**		**Question 4**		**Question 5**	
Bond btwn 2+ atoms	61	Covalent share, ionic take	58	No. of H	46	Nothing	48	Nothing	15
Bond & can't be physically separated	7	Ionic same, covalent high energy	1	Nonsense/Nothing	32	Electronegativities	6	Charges/poles	17
Attraction/force holds together	35	Electronegativities	16	No. valence e	4	Different elements	29	E sharing	66
Atoms share e	33	Ionic same e, covalent multiple	1	Methane has more elements	1	Stability	2	Stability	4
Energy link	1	No of atoms	4	No. of e	6	Metal vs. nonmetal	10	No. atoms	2
Share e to fill octet	1	No of e	2	Smaller	2	Polarities	2	Electronegativities	23
Nothing	1	Nonsense/Nothing	10	Polarities	7	Valence e	6	Attraction	6
Mix together	1	Difference in energy	1	Different elements	19	Atomic masses	1	Multiple e shared	1
		Type of atom	24	No. of atoms	8	Ionic vs. covalent	19	No. of e	2
		Charges	6	Ionic vs. covalent	3	Lone pairs	2	Pull on atoms	1
		Ionic ions, covalent share	8	Charges	3	Weak bonds	3	Uneven bonds	1
		Ionic gain, covalent lose	1	Lone pairs	1	Charges	2		
		Ionic ions	3	No. open spots	1	E repulsions	1		
		Covalent share	1	Stability	4	Size	7		
				Bond lengths	1				

Table 3.5, Reactions and Reactivity Test Results

Question 1		Question 2		Question 3		Question 4		Question 5	
Unchanged	7	Increase/same	40	electron movement	5	attractions	26	No (noble gases don't need e)	17
Break (ionic)	16	Same/increase	10	attraction	39	electronegativity/polarity	26	No (bond polarity)	15
Stay together (not inter)	1	Increase/increase	59	valence e	9	Nonsense/Nothing	27	No (bonds/properties incompatible)	12
Spread apart (too small)	2	Decrease/decrease	4	stability/lower energy	16	electrons	13	No	20
Break (bond w/ water)	72	Decrease/same	1	difference properties	14	Energy	14	No (stable already)	21
Break	21	Increase/decrease	6	Nothing/Nonsense	20	Unpaired e	2	Nonsense/Nothing	11
Goes away/dissolves	2	Same/same	13	bonds breaking	4	distance	2	No (similar charges/properties)	10
Unchanged (spread apart)	1	Decrease/increase	2	fulfill octet	14	Similar bonds	4	Yes (high pressures/forces)	4
Weaken (spread apart)	5	Nothing	2	e sharing	7	water	4	Yes (depends)	6
Break (stability)	1	Same/decrease	1	to create bonds	9	atoms	1	No (weak attractions)	9
Mix w/ water	1			Neutrality	1	catalyst	4	No (charges)	3
Strengthen	2					temperature	1	No (valence needs to match)	[illegible]
Spread apart	2					Type of bond	4	No (too much shielding)	[illegible]
Nonsense/Nothing	4					concentration	2	No (concentration)	[illegible]
Break (melt)	1					Vapor pressure	1	Yes	6
						Magnetism	1	Yes (octet rule)	1
						Acid/Base	1		
						Octet rule	2		
						Movement	2		

Table 3.6, Intermolecular Forces Pretest Results

Question 1		**Question 2**		**Question 3**		**Question 4**		**Question 5 part 1**		**Question 5 part 2**	
Surface tension	45	High altitude = high pressure	9	Molecules condense, water freezes	31	Evaporates	129	Oil repels water	10	Increased viscosity	4
Nothing	17	High altitude	22	Nothing	9	Oxygen evaporates	2	Nothing	26	Break surface tension	29
Bonds stronger than gravity	6	Lower pressure	47	Molecules come together	55	Nonsense	2	Can't break water's bonds	1	Increased surface tension	1
Sturdy center	1	Water has lower boiling point	16	Explosions	7	Vapor pressure	1	Less dense than water	36	Increase volume	1
Friction/stuck to cup	10	Less oxygen	10	Expansion	1	Break apart	1	Doesn't break surface tension	39	No change	1
Force from cup	2	Thin air	15	Cool down	1	Move into air	1	High surface area	16	Increase density	2
Air resistance stronger than gravity	2	Higher boiling point	10	Impossible	2			High momentum	5	Decrease density	2
Water bonds hold together	26	Nothing	7	Heat/speed up	28			Little water contact	1	Pulls in bug	50
Sticky	4	Less gravity	1	Break apart	1			Force up = force down	3		
High pressure	3							Bug sticks to water skin	3		
Has a meniscus	14										
Gravity	7										
Illusion	1										

Table 3.7, Gas Laws Pretest Results

Question 1		**Question 2**		**Question 3**		**Question 4**	
Difference in pressure (in/out)	22	Gas escapes	3	Gas escapes	101	Freezes water	67
Atoms can't come back together	1	Pressure up	2	Gas loses energy	5	Increases pressure	20
Nonsense/Nothing	26	Gas condenses	52	Pressure	11	Nonsense/Nothing	42
Increased pressure (from cooling)	1	Gas moves slower	29	Gas more stable	1	Cools air	2
Fast heat change	10	Balloon contracts	24	Nonsense/Nothing	9	Freezes water (w/ cold air)	10
Gas laws	1	Cold makes things contract	12	Balloon shrinks	2	Pressurized water	1
Cold makes things shrink/crush	8	Molecules freeze	8	Gas reacts	1	Crushes ice	6
Temperature difference	11	Gas less effective	1	Gas disintegrates	1	Reacts water	2
Gas condenses	42	Nonsense/Nothing	7	Gas less dense	1	Uses hydrates	1
Forces	2	Gas more dense	7				
Gravity	2	Pressure difference	6				
Density difference	6	Lower energy	3				
		Particles get smaller	1				
		Gas less dense	1				

Question 5 part 1		**Question 5 part 2**		**Question 5 part 3**		**Question 6**		**Question 7**	
Hydrogen	19	Hydrogen	84	Hydrogen	12	Gas moving	1	Gases rise (density)	48
Oxygen	21	Oxygen	14	Oxygen	102	Space/space	17	Gases rise (hot)	24
Same	76	Same	21	Same	4	Nonsense/Nothing	38	Gases rise (hot = fast)	16
Nothing	16	Nothing	14	Nothing	14	air in room has other gases	11	Nonsense/Nothing	22
						More O in space	2	Gases rise	4
						space/N	2	gases rise (volume)	8
						Bonds	41	Gases rise (density Wrong)	1
						Forces	3	Heat falls	1
						space/other particles	15	Heat rises (convection)	1
						Forces/other particles	4	Hi P to low P	4
						Density	1	Combutted	1
								Gases fall	1
						LDF/DD = bonds		Mixing	1
								Heat expands	1

Table 3.8, Thermodynamics Pretest Results

Question 1		Question 2		Question 3		Question 4		Question 5	
Metal good conductor (plastic poor/insulator)	34	Endothermic	43	Warm	9	gained	10	Taken in	22
Nothing	25	Exothermic	84	Warm, energy up	2	gained, particles faster	4	Taken in, particle movement	4
Metal absorbs energy	12	Neither	3	Warm, particle movement	7	Lost, energy in match	8	Released	22
Metal has stronger bonds	9			Warm, heat = energy	11	Lost, energy released	30	Taken in, weak bonds	3
Metal is denser	7			Cool, absorbs energy by reaction	36	Gained, energy needed	8	Released, heat out	5
Metal loses heat faster	6			Warm, energy absorbed	28	Neither	16	Nothing	6
Plastic absorbs energy	4			Cool, atoms bonding	1	Gained, fire adds energy	3	Released, energy moves	1
Metal has more bonds	2			Cold, heat exerted	1	Gained, energy = fire	16	Taken in, energy needed	32
Metal = endothermic, plastic = exothermic	4			Cold	11	Gained, friction = energy	6	Both	7
Metal has a higher melting point	3			Cold, water freezes	2	Nothing	7	Released, bonds store energy	16
Metal more sensitive	1			Cold, heat lost	9	Lost, particles lost	1	Taken in, takes energy from bond	1
Less atom movement	2			Cold, heat not exerted	6	Lost	16	Released, bonds need energy	1
Different	2			Cold, no changes	1	Gained, gained by match	3	Released, losing particles	1
Metal holds cold	1			Warm, endothermic	2	Lost, T up = E down	1	Taken in, bond replaced	1
Inside of metal is warm	1			Neither	4	Gained, bonds gain energy	1	Taken in, change to start breaking	1
Air sticks to metal	1							Taken in, heat created	1
Metal = exothermic, plastic = endothermic	2							Released, e lost	1
No of moles	1							Taken in, unbonded = high E	1
Metal holds heat	7							Taken in, temp up	4

Table 3.9, Solutions and Solubility Pretest Results

Question 1		**Question 2**		**Question 3**		**Question 4**		**Question 5**	
salt breaks down water	1	No one got this correct		Nonsense	19	Doesn't matter	13	salty	1
melting point of salt lower	2			dies, chemical rxn	36	Hot day	78	salty, from salt water	26
ice melts/dissolves	27			dies, salt absorbs water	27	Cold day	9	not salty, salt melts ice	5
salt lowers mp of water	17			shrivels, equilibrate salt levels/osmosis	8	Nonsense	12	not salty, ice can't form w/ salt in it	41
chemical reactions melt ice	36			salt dissolves	5			not salty, salt is more dense	9
salt lowers melting time	5			salt enters slug	1			nonsense	16
salt intibits ice bonds	8			slug melts	2			no, water covers salt	6
nonsense	6			dies, environment change	16			no, salt evaporates	2
salt absorbs water	11							no	7

Table 3.10, posttest results 2010

There were 130 student responses recorded for this posttest. The correct response is represented with italics for each question.

Question	Choice A	Choice B	Choice C	Choice D	Choice E	Question	Choice A	Choice B	Choice C	Choice D	Choice E
1	6	2	*115*	4	3	**21**	*75*	6	28	20	1
2	3	*96*	2	27	2	**22**	2	14	30	*35*	49
3	21	19	0	*89*	1	**23**	*116*	0	4	2	8
4	*106*	23	1	0	0	**24**	7	1	12	30	*80*
5	50	*80*	0	0	0	**25**	36	*41*	6	24	23
6	*73*	1	48	1	6	**26**	*97*	19	14	0	0
7	62	19	*42*	0	6	**27**	10	13	6	4	*97*
8	2	7	6	*94*	21	**28**	19	9	1	*101*	0
9	47	*77*	2	1	3	**29**	1	23	13	18	*75*
10	*74*	2	8	41	5	**30**	*95*	17	3	12	3
11	3	1	1	5	*120*	**31**	69	*54*	2	4	1
12	3	9	10	5	*102*	**32**	*44*	52	21	11	1
13	*84*	21	6	12	7	**33**	2	*108*	1	14	5
14	*64*	2	0	16	48	**34**	*71*	20	14	5	20
15	0	*121*	1	2	6	**35**	*103*	25	2	0	0
16	41	0	*85*	4	0	**36**	6	9	4	*110*	1
17	27	10	3	*87*	1	**37**	25	24	39	*41*	0
18	*120*	8	0	2	0	**38**	*101*	4	11	0	14
19	10	2	3	*107*	8	**39**	2	26	0	*97*	5
20	22	0	*39*	42	26	**40**	3	19	30	25	*52*

Table 3.11, pretest results 2011

There were 103 student responses recorded for this pretest. The correct response is represented with italics for each question.

Question	Choice A	Choice B	Choice C	Choice D	Choice E	Question	Choice A	Choice B	Choice C	Choice D	Choice E
1	12	6	*82*	1	1	**21**	*51*	10	19	14	9
2	2	*70*	13	15	3	**22**	3	29	22	*19*	30
3	32	51	1	*19*	0	**23**	*56*	1	4	10	32
4	*87*	12	4	0	0	**24**	25	2	16	41	*19*
5	49	*54*	0	0	0	**25**	19	*39*	14	18	13
6	*47*	4	41	2	9	**26**	*39*	41	20	3	0
7	54	24	*14*	6	5	**27**	5	27	6	6	*59*
8	8	20	17	*44*	14	**28**	14	32	7	*47*	2
9	29	*52*	0	13	9	**29**	3	31	25	21	*23*
10	*56*	5	22	19	1	**30**	*55*	9	3	32	4
11	2	2	1	11	*87*	**31**	41	*30*	19	8	5
12	8	9	23	4	*58*	**32**	*12*	44	32	11	4
13	*33*	19	15	21	15	**33**	3	*86*	2	7	5
14	*54*	25	3	11	10	**34**	*36*	8	14	6	39
15	0	*38*	36	6	23	**35**	*47*	45	10	0	1
16	44	4	*4*	35	16	**36**	21	17	13	*40*	12
17	31	20	22	*22*	8	**37**	15	20	62	*6*	0
18	*31*	19	11	36	6	**38**	*27*	17	45	5	9
19	25	11	17	*23*	27	**39**	2	61	2	*9*	29
20	18	0	*55*	17	13	**40**	14	22	29	19	*19*

Table 3.12, posttest results 2011

There were 103 student responses recorded for this posttest. The correct response is represented with italics for each question.

Question	Choice A	Choice B	Choice C	Choice D	Choice E	Question	Choice A	Choice B	Choice C	Choice D	Choice E
1	5	3	*83*	2	0	**21**	*62*	4	12	13	2
2	4	*67*	6	14	1	**22**	4	25	15	*24*	25
3	33	11	0	*49*	0	**23**	*85*	0	0	5	3
4	*70*	20	3	0	0	**24**	2	1	15	20	*55*
5	37	*56*	0	0	0	**25**	24	*20*	5	40	4
6	*50*	1	40	1	1	**26**	*56*	25	12	0	0
7	66	9	*12*	1	5	**27**	3	6	3	0	*81*
8	5	8	7	*52*	20	**28**	5	8	0	*77*	3
9	28	*53*	1	6	5	**29**	4	6	13	13	*57*
10	*60*	5	11	16	1	**30**	*86*	3	2	2	0
11	4	0	0	5	*84*	**31**	45	*31*	10	3	4
12	6	13	13	3	*58*	**32**	*23*	26	32	11	1
13	*63*	12	4	8	6	**33**	0	*76*	2	10	5
14	*74*	5	0	2	12	**34**	*43*	11	5	6	28
15	0	*79*	5	0	9	**35**	*58*	27	8	0	0
16	22	3	*65*	3	0	**36**	4	4	7	*77*	1
17	23	2	5	*61*	2	**37**	13	24	26	*30*	0
18	*86*	3	1	3	0	**38**	*40*	3	41	3	6
19	10	3	1	*72*	7	**39**	4	47	1	*12*	29
20	12	0	*42*	24	15	**40**	13	20	31	13	*16*

Table 3.13, pretest results 2011, Percentage Form

There were 103 student responses recorded for this pretest.

Question	Choice A	Choice B	Choice C	Choice D	Choice E	Question	Choice A	Choice B	Choice C	Choice D	Choice E
1	12	6	80	1	1	**21**	50	10	18	14	9
2	2	68	13	15	3	**22**	3	28	21	18	29
3	31	50	1	18	0	**23**	54	1	4	10	31
4	84	12	4	0	0	**24**	24	2	16	40	18
5	48	52	0	0	0	**25**	18	38	14	17	13
6	46	4	40	2	9	**26**	38	40	19	3	0
7	52	23	14	6	5	**27**	5	26	6	6	57
8	8	19	17	43	14	**28**	14	31	7	46	2
9	28	50	0	13	9	**29**	3	30	24	20	22
10	54	5	21	18	1	**30**	53	9	3	31	4
11	2	2	1	11	84	**31**	40	29	18	8	5
12	8	9	23	4	57	**32**	12	43	31	11	4
13	32	18	15	20	15	**33**	3	83	2	7	5
14	52	24	3	11	10	**34**	35	8	14	6	38
15	0	37	35	6	22	**35**	46	44	10	0	1
16	43	4	4	34	16	**36**	20	17	13	39	12
17	30	19	21	21	8	**37**	15	19	60	6	0
18	30	18	11	35	6	**38**	26	17	44	5	9
19	24	11	17	22	26	**39**	2	59	2	9	28
20	17	0	53	17	13	**40**	14	21	28	18	18

Table 3.14, posttest results 2011, Percentage Form

There were 103 student responses recorded for this posttest.

Question	Choice A	Choice B	Choice C	Choice D	Choice E	Question	Choice A	Choice B	Choice C	Choice D	Choice E
1	5	3	89	2	0	**21**	67	4	13	14	2
2	4	73	7	15	1	**22**	4	27	16	26	27
3	35	12	0	53	0	**23**	91	0	0	5	3
4	75	22	3	0	0	**24**	2	1	16	22	59
5	40	60	0	0	0	**25**	26	22	5	43	4
6	54	1	43	1	1	**26**	60	27	13	0	0
7	71	10	13	1	5	**27**	3	6	3	0	87
8	5	9	8	57	22	**28**	5	9	0	83	3
9	30	57	1	6	5	**29**	4	6	14	14	61
10	65	5	12	17	1	**30**	92	3	2	2	0
11	4	0	0	5	90	**31**	48	33	11	3	4
12	6	14	14	3	62	**32**	25	28	34	12	1
13	68	13	4	9	6	**33**	0	82	2	11	5
14	80	5	0	2	13	**34**	46	12	5	6	30
15	0	85	5	0	10	**35**	62	29	9	0	0
16	24	3	70	3	0	**36**	4	4	8	83	1
17	25	2	5	66	2	**37**	14	26	28	32	0
18	92	3	1	3	0	**38**	43	3	44	3	6
19	11	3	1	77	8	**39**	4	51	1	13	31
20	13	0	45	26	16	**40**	14	22	33	14	17

Table 3.15, Category Analysis of Questions

Each question is listed by category. The percentage correct on the 2011 pretest, 2010 posttest, 2011 posttest, and percentage gain from pretest to posttest are displayed. The average gain by each category is also listed.

Question	Category	2011 Pre	2010 Post	2011 Post	2011 Gain	2010 Gain	Category Gain
11	as	0.84	0.92	0.90	0.06	0.08	0.19
12	as	0.57	0.79	0.62	0.06	0.22	
13	as	0.32	0.65	0.68	0.36	0.33	
14	as	0.52	0.49	0.80	0.27	-0.03	
15	bo	0.37	0.93	0.85	0.48	0.56	0.45
16	bo	0.04	0.65	0.70	0.66	0.62	
17	bo	0.21	0.68	0.66	0.44	0.47	
18	bo	0.30	0.92	0.92	0.62	0.62	
19	bo	0.22	0.82	0.77	0.55	0.60	
20	bo	0.53	0.30	0.45	-0.08	-0.23	
24	gl	0.18	0.62	0.59	0.41	0.43	0.24
28	gl	0.46	0.78	0.83	0.37	0.32	
29	gl	0.22	0.58	0.61	0.39	0.35	
30	gl	0.53	0.73	0.92	0.39	0.20	
31	gl	0.29	0.42	0.33	0.04	0.12	
32	gl	0.12	0.34	0.25	0.13	0.22	
33	gl	0.83	0.83	0.82	-0.02	0.00	
9	grx	0.50	0.59	0.57	0.07	0.09	0.08
10	grx	0.54	0.57	0.65	0.10	0.03	
23	imf	0.54	0.89	0.91	0.37	0.35	0.33
27	imf	0.57	0.75	0.87	0.30	0.17	
2	pc	0.68	0.74	0.73	0.05	0.06	0.11
3	pc	0.18	0.68	0.53	0.34	0.50	
5	pc	0.52	0.62	0.60	0.08	0.09	
25	pc	0.38	0.32	0.22	-0.16	-0.06	
26	pc	0.38	0.75	0.60	0.22	0.37	
1	pn	0.80	0.88	0.89	0.09	0.08	0.04
7	pn	0.14	0.33	0.13	-0.01	0.19	
4	rx	0.84	0.82	0.75	-0.09	-0.03	-0.01
22	rx	0.18	0.27	0.26	0.07	0.08	
21	sol	0.50	0.58	0.67	0.17	0.08	0.09
38	sol	0.26	0.78	0.43	0.17	0.51	
39	sol	0.09	0.75	0.13	0.04	0.66	
40	sol	0.18	0.40	0.17	-0.01	0.22	

Table 3.15, Continued

Question	Category	2011 Pre	2010 Post	2011 Post	2011 Gain	2010 Gain	Category Gain
6	sto	0.46	0.57	0.54	0.08	0.11	0.11
8	sto	0.43	0.72	0.57	0.14	0.30	
34	th	0.35	0.55	0.46	0.11	0.20	0.25
35	th	0.46	0.79	0.62	0.17	0.34	
36	th	0.39	0.85	0.83	0.44	0.46	
37	th	0.06	0.32	0.32	0.26	0.26	

The categories can be defined as follows:

as: Atomic Structure

bo: Bonding

gl: Gas Laws

grx: Gas Forming Reactions

imf: Intermolecular Forces

pc: Properties of Phases and Phase Changes

pn: The Particulate Nature of Matter

rx: Properties of Chemical Reactions

sol: Solutions and Solubility

sto: Stoichiometry and Stoichiometric Ratios

th: Thermodynamics

CHAPTER IV

DISCUSSION

The following is a summary of each question stem, followed by the response answers. Each distractor is explained as well as the misconception that the distractor represents. The questions are followed, in bold, by the percentage of students who answered the question correctly on the 2011 pretest followed by the 2010 posttest, and finally the 2011 posttest. The correct answer is italicized.

Question One:

If you had a copper penny, how many atoms of copper would there be?

a. Many **12% | 5% | 5%**
b. One atom **6% | 2% | 3%**
c. *It depends on the mass of the penny* ***80% | 88% | 89%***
d. It depends on the volume of the penny **1% | 3% | 2%**
e. Twenty-nine **1% | 2% | 0%**

This stem is directed at two common misconceptions; the size of an atom and the procedure to determine how many atoms are present in any given amount of matter. Most students were able to properly identify that there is a relationship between mass and amount of atoms (choice C) on both the pre- and posttests, but misconceptions about this basic idea still exist as twenty percent of the students answered incorrectly. Because atoms are too small to be visible, the idea that there are too many to count arises. That is the scenario in distractor A. This was the second most popular distractor for students on the pretests as well as the posttests. In a student's mind, a million atoms seems like a large, uncountable number of atoms that would be appropriate for the number of atoms in a penny (a billion was another popular answer on the surveys). The student understands that the atom is small, but has no concept of how small. Distractor B shows either little to no understanding of what an atom is or that the student has confused the terms atom and element, as a pure copper penny would only have one type of atom in its

structure. Distractor D arises from the misconception that physical changes, like bending or shaping the penny, will alter the internal make-up of the penny itself. The final distractor, E. 29, shows that the student has confused the atomic number (number of protons) in copper with the number of atoms that would be present in a sample of copper. It is a similar confusion to that made for distractor B.

Question Two:

If you have a sample of salt water and you heat it in a closed container until all the water has evaporated, what is present in the container and how will the mass have changed?

a. Salt alone, mass stays the same **2% | 2% | 4%**
b. *Salt and water vapor, mass stays the same **68% | 74% | 73%***
c. Salt alone, mass decreases because there is no water **13% | 2% | 7%**
d. Salt and water vapor, mass decreases because gas is less dense than water (liquid) **15% | 21% | 15%**
e. Salt, hydrogen, and oxygen gas present, mass goes through a small change **3% | 2% | 1%**

This stem drives at the concepts of physical versus chemical change, the law of conservation of mass, and the idea of a closed container. Students commonly confuse physical and chemical changes, especially when it comes to evaporation. As the gas is not visible to them, the first conclusion is that it has disappeared. This also addresses the law of conservation of mass. Because gas is less dense than water, students believe that it will have less mass as well (distractor D). The final idea tested is that gas cannot escape a closed container. Much of a student's experience with evaporation (cooking, hot water baths, etc.) has been with open containers where mass is lost to the surroundings through evaporation.

Most students were able to identify that the mass would stay constant and that salt and water vapor present (choice B). On the pretests, students were fairly evenly split between thinking the mass would decrease due to the absence of water (distractor C) and that the mass would decrease because water is less dense (distractor D). The distribution of students' answers changed on the posttest, though. After the students had been taught gas laws and worked with closed containers in lab, distractor C became much less popular, but distractor D became a more popular option. This demonstrates that after being

taught about the characteristics of gases, students better understand that gases are less dense than liquids, but they do not understand that a sample of gas from an evaporated liquid will have the same mass, despite its lower density. Distractor A, which states the mass would stay the same but only salt would be present, shows that the student understands the law of conservation of mass applies, but does understand what happened to the liquid water. Distractor E, which states the water would split into hydrogen and oxygen through evaporation, shows that the student possess the misconception that a chemical reaction occurred with the water molecules splitting into their component elements.

Question Three:

During the process of evaporation, what is happening to the molecules of a liquid?

a. Molecular bonds are breaking **31% | 16% | 35%**
b. Molecules vibrate faster **50% | 15% | 12%**
c. Liquid rises **1% | 0% | 0%**
d. Intermolecular bonds are breaking ***18% | 68% | 53%***
e. Liquid decreases **0% | 1% | 0%**

This is another question addressing physical and chemical changes. Many students believe that through evaporation, molecular bonds within a molecule are breaking. The concept of intermolecular forces, or attractive bonds between molecules, is difficult for students to grasp. This is especially true when they do not fully understand the concept of intramolecular bonds to begin with. Intramolecular bonds can be defined as the covalent and ionic bonds which constitute a molecular unit of the substance. Since intermolecular forces is not a topic commonly discussed before first-year chemistry, most students answered this incorrectly on the pretest. However, most students correctly answered this question on the posttest. Distractor A shows that the student has the misconception that as a substance evaporates the bonds between the atoms within the molecule break. This was the second most popular choice on both the pre- and posttests, but the number of students who selected it dropped significantly after the topic of intermolecular bonds was addressed in class. Distractor B, which states the molecules vibrate faster, shows the understanding that additional heat leads to faster molecular vibration (and movement), but it

misses the idea that during evaporation the breaking of intermolecular bonds absorbs the additional energy. Distractor C, which states that liquid rises, shows the understanding that gases that are less dense than air will rise. It even partially addresses the idea that a boiling liquid will have a level above the non-boiling liquid (as it has air bubbles in it). Choice D, which states that intermolecular bonds are breaking, represents the correct choice. Distractor E, which states the liquid decreases, is correct in the sense that the water level will be lower after evaporating off some water, but it does not fully explain the process.

Question Four:

If you were to take a sample of pure gold, dissolve it through a number of chemical reactions, and end up with a sample of only gold atoms, would this be a pure or impure sample of matter?

a. Pure ***84% | 82% | 75%***
b. Impure **12% | 18% | 22%**
c. Can't tell **4% | 1% | 3%**

This stem drives at two common problems with student understanding. The first issue is that once matter goes through a chemical change, it is no longer pure. The second is that the student does not fully read the question to see that it is pure in both cases. The idea that a chemical reaction makes something impure results from a misunderstanding of the definition of pure and impure. The terms pure and natural or unadulterated are very often interchangeable in a student's mind where both pure and natural represent how something would be found in nature. The idea of chemically reacting something changes how the substance exists in nature, so it is therefore not pure. The interesting result from this question is that the students answered this question correctly more often on the pretest than on the posttest either year. This reflects a problem that after chemical reactions are discussed at length, the student relies on his or her experience (that reactions generally produce impure products) rather than closely reading the wording of the question, which states the product is pure.

Question Five:

An individual atom can exist in either the solid, liquid, or gas phases (true or false)?

a. True **48% | 38% | 40%**
*b. False **52% | 62% | 60%***

This stem addresses misconceptions relating to the definitions of phases and aggregates of particles. If there were only one atom, it cannot exist in either the solid or liquid phase, as these phases are defined by the intermolecular forces that exist in an aggregate of particles of the substance. One atom, existing by itself, is therefore in the gas phase by definition. Students (as well as faculty) were split on both the pre- and posttests regarding this question, favoring the idea that the statement is false. The problem arises from the distinction between an aggregate and an individual atom.

Question Six:

Will one gram of hydrogen gas and one gram of chlorine gas react completely? Use the following balanced equation: $H_2 + Cl_2 \rightarrow 2\ HCl$

*a. No, because hydrogen and chlorine have different atomic masses **46% | 57% | 54%***
b. No, because the reaction is balanced 1:1 **4% | 1% | 1%**
c. Yes, because the reaction is balanced 1:1 **40% | 37% | 43%**
d. Yes, because they will **2% | 1% | 1%**
e. Yes, because they balance to two **9 % | 5% |1 %**

This stem and the two that follow regard the reaction of the formation of hydrogen chloride from its elements. These questions require the student to understand how and when a balanced chemical equation can be used as well as the difference between a mole ratio and a mass ratio. Many students commonly confuse the idea that a gram and a mole are both measures of amount of particles (directly). The mole references the number of particles, whereas mass (grams) measures the amount of matter in the particles. The distractors for this question also address the incorrect idea that if a reaction has a one-

to-one mole ratio through a balanced chemical equation anything else relating to the reaction will happen at a one-to-one ratio as well.

In both the pre- and posttests, the students were fairly divided between correctly identifying that the different molar masses will confer a ratio other than one to one for a complete reaction (distractor A) and that the reaction will proceed to completion because the reaction is balanced at a one to one ratio (distractor C). The student understands that the balanced equation determines the ratio at which substances react, but not that a gram and a mole are proportionally different measures for different substances. Most all students would be able to identify that hydrogen and chlorine gas have different molar masses, but when asked the question in this fashion, without forcing the students to look up the molar masses to answer the question, many will disregard this fact. Distractors B, D, and E show little understanding of the question and what a mole ratio relates to. All three of these choices were unpopular on both the pre- and posttests.

Question Seven:

If there was a bottle containing one molecule of hydrogen gas and one molecule of chlorine gas, would they react to make two molecules of hydrogen chloride gas? (see equation above)

a. Yes, because that follows the balanced equation (they are 1:1) **52 % |48 % |71 %**
b. No, it will only make one molecule of hydrochloric acid gas **23 % |15 % | 10%**
c. *No, the likelihood of the two particles colliding is too small* ***14 % |33 % |13 %***
d. Yes, they have similar charges **6 % |0 % |1 %**
e. Yes, but only if the pressure of the bottle were the same throughout **5 % |5 % |5 %**

This stem gets to the concept of the size of a molecule in relationship to a container and the practicality of a reaction under such conditions. The likelihood that two molecules would collide with the correct speed and orientation in a container of just two individual molecules is extremely improbable (distractor C). Most students follow the balanced equation and state that this is true (distractor A). This was true on both the pre- and posttests. This ratio would be followed if the particles were to react, but as there are

only individual particles, there is an extremely small likelihood of reaction. Interestingly, the next most popular choice was that there will only be reaction to form one molecule of hydrogen chloride gas (choice B). This shows that the student believes that one molecule and one other molecule cannot react to make two molecules. This misconception persisted in the posttest analysis, as well. Choice D, that they have similar charges, was hardly chosen on the pre- and posttest, and shows that the student understands that charge will affect the likelihood of reaction, but not how. Choice E, yes if the pressure were constant throughout, similarly shows that the student understands that pressure will affect gasses, but not how a constant pressure will affect gases.

Question Eight:

If you had less than one mole of hydrogen gas and less than one mole of chlorine gas in a container, would they react to make hydrogen chloride gas? (see equation above)

a. Yes, because that follows the balanced equation (they are 1:1) **8 % | 2 % | 5 %**
b. No, you need a full mole for them to react **19 % |5 % |9 %**
c. No, because they are not at a 1:1 ratio **17 % |5 % | 8 %**
d. Yes, the specific amount doesn't matter (assuming there are more than 0 molecules) ***43% |72% | 57%***
e. Yes, if the amounts are equally less than one mole **14 % |16 % |22 %**

This stem again addresses the mole ratio and whether or not students understand that it is just a ratio and does not specify amount. As long as there is enough of each reactant to have a collision and a reaction, then the specific amount of each reactant doesn't matter for there to be a reaction. This question differs from question number 6 as well because it does not talk about there being a complete reaction, only that a reaction occurs. Distractor A, Yes because the ratio is one to one, shows that the student understands the mole ratio, but not how the mole ratio relates to amounts in a reaction. Distractor B, No, you need a full mole, shows that the student thinks that the mole ratio has one mole "minimums" so to speak, where if there are less than that one mole amount, a reaction cannot occur. This choice was popular on the pretest, but was significantly reduced on the posttest. Distractor C, No, it isn't one to one, demonstrates a similar misunderstanding to choice B. If there aren't exact one to one

amount ratios, the reaction will not occur. This choice could also show a misunderstanding of the idea of a reaction taking place compared to a completion reaction. Distractor E, Yes, so long as the amounts are equally less than one mole, shows that the student realizes that there isn't a one mole minimum in order for a reaction to occur, but that the student doesn't understand that the amounts of each reactant do not need to be the same for a reaction to occur. Interestingly, the proportion of students selecting this distractor went up from the pretest to the posttest. Again, this shows the misunderstanding or misreading that the reaction in this question is not a completion reaction.

Question Nine:

A box of matches is measured to have a mass of 500 g. You then strike all the matches and put the ashes back in the box. You find the mass to be 490 g. Where did the 10 g of mass go?

a. The mass was converted to energy (from the chemical reaction) **26 % |36 % |30 %**
b. The mass was converted to carbon dioxide ***50 % | 59 % | 57 %***
c. The mass was lost to the reaction **0 % |2 % |1 %**
d. The mass was converted to carbon **13 % |1 % |6 %**
e. This is not possible, mass is conserved through chemical reactions **9 % |2 % | 5 %**

This stem addresses the concepts of the law of conservation of mass, the mass of gaseous products, and the idea of an open versus a closed container. This problem is different from the scenario in question two, as the container is not closed and there is mass lost to the surroundings. The product is a colorless gas (carbon dioxide and carbon monoxide), so again there is nothing visible for the student to realize where that mass might have gone. Finally, a misunderstanding of the law of conservation of mass versus the law of conservation of energy could lead students to think that the mass is either converted into energy (distractor A) or that it is an impossible reaction because the mass is not apparently conserved through the reaction (distractor E). Once students have learned about the law of conservation of energy (by the time of the posttest), the proportion of students selecting distractor A increases, showing that students understand that the law of conservation of energy applies, but not on what scale. If the 10 g of mass were converted into energy, it would result in roughly a 9×10^{11} kJ release in energy, more than the

energy of the explosion of the atomic bombs dropped in World War Two. The amount of mass converted to energy in this scenario is insignificant with respect to the gas produced. Distractor C, that the mass is gone, suggests that the student does not understand the reaction or where the mass could have possibly gone. Mass being converted to carbon, distractor D, suggests that the student realizes that carbon is part of the reaction, but thinks that the burnt match sticks are missing some carbon or that the carbon was decreased off through the process of striking the matches, not through the production of a carbon containing gas.

Question Ten:

If you measure the mass of an iron bar to be 10.0 grams on a balance and then allow the bar to rust, will the mass go up, down, or stay the same as the bar rusts?

a. *The mass will go up from the added oxygen* ***54 % |57 % |65 %***
b. The mass will stay the same, there are no overall changes to the chemical formula **5 % | 2 % |5 %**
c. The mass will stay the same, the law of conservation of mass applies **21 % |6 % |12 %**
d. The mass will go down, rust corrodes metal **18 % |32 % |17 %**
e. The mass will go up, rust is heavier than iron **1 % |4 % |1 %**

This stem is similar to question number nine, but in this scenario, the gas is a reactant rather than a product in the reaction. It addresses the same misconceptions and also requires the student to understand something about the process of rusting. Distractor B, which states that the mass stays the same because there is no change, represents a misunderstanding of the process of rusting and the fact that rust and iron are different substances. The law of conservation of mass is again addressed in distractor C, that the mass stays constant according to the law of conservation of mass. This is a popular choice on the pretest because the law of conservation of mass is stressed in previous coursework, but the student fails to take into account the mass of the colorless oxygen gas. Distractor D, the mass decreases as rust corrodes metal, represents the idea that rust is iron that has fallen apart or been degraded. Because of the brittle characteristics of rusted iron, students fall back on personal experience that some of the iron is gone or "eaten away" without being deposited elsewhere. The percentage of students

choosing this distractor stayed constant for one year and went up for another, showing that this is a particularly hard misconception to dislodge. Distractor E, mass increases as rust is heavier than iron, is true, but does not show that the student has an understanding of where that added mass comes from and is therefore not the best choice.

Question Eleven:

In-between the nucleus and the electrons in an atom, there is/are:

a. Bonds **2 % |2 % |4 %**
b. Plasma **2 % | 1 % |0 %**
c. Gas **1 % |1 % |0 %**
d. Protons and neutrons **11 % |4 % |5 %**
e. *Empty space* ***84 % |92 % |90 %***

This stem drives at the student's understanding of the atomic model. Many students think that there is enough space between the protons and core electrons to fit other atoms or molecules. The correct choice, E, empty space, is all that exists between the nucleus and the core electrons. Distractors B – D all present something with mass that takes up more space than is present in the atom. Distractor A, bonds, is ambiguous because attractive forces do not take up space, making the answer incorrect. Most students answered this question correctly in both the pre- and posttests.

Question Twelve:

What was wrong with Bohr's model?

a. Nothing **8 % | 2 % |6 %**
b. It was two dimensional **9 % | 7 % |14 %**
c. There weren't any electrons **23 % | 8 % |14 %**
d. It wasn't very accurate **4 % |4 % |3 %**
e. *Electrons do not have fixed paths* ***57 % |79 % | 62 %***

This stem addresses the students understanding of Bohr's atomic model. Bohr's atomic model is often referred to as the solar system model, with electrons orbiting the nucleus on relatively fixed paths about the nucleus. Although this analogy makes it easier to visualize an atomic model with electrons at fixed energy levels, it also introduces a number of misconceptions into general understanding of the model and electrons on the whole. First of which, the idea that electrons are relatively fixed in their path around the nucleus and that they travel in circular orbits as planets might orbit a star. This makes it more difficult for students to grasp valence shells and the quantum model of the atom in later instruction. Another misconception associated with Bohr's model is its relatively two dimensional structure, as our solar system is relatively two dimensional with respect to planetary orbits (distractor B). The fact that most Bohr model representations are seen on paper (two dimensional) in books or drawn on paper or on the board perpetuates this misconception. After students have been specifically instructed on Bohr's model, this choice became more popular. Distractor C, there weren't any electrons, shows that the student understands that there is a problem with the way in which the Bohr model addresses electrons, but not that the problem is with the paths of the electrons (choice E). This was the most popular incorrect choice on the pretest, which is not surprising as most students were never exposed to the quantum model in any depth previous to the course. Distractor A, nothing, and C, Bohr's experiment was in error, show that the student does not understand what Bohr's model is nor how it fits into atomic theory.

Question Thirteen:

What does it mean for energy to be quantized?

a. *It is defined by quantities or packets of energy* ***32 % |65 % |68 %***
b. It is measured in terms of light waves **18 % |16 % |13 %**
c. The light waves have been converted to mass **15 % |5 % |4 %**
d. Energy is being transferred **20 % |9 % |9 %**
e. Energy is contained **15 % | 5 % |6 %**

This stem addresses the student's understanding of the term "quantized." Students have many ideas of the quantum model of the atom that they have picked up through various sources. Most students demonstrate that they have an idea that light and energy is incorporated into the model, but not how. Distractor B, it is measured in terms of light waves, and C, light waves have been converted to mass, address these misconceptions. Distractors D, energy is being transferred, and E, energy is contained, suggest that the student does not understand how energy relates to the quantum model nor what the term "quantized" means. The pretest showed a fairly even distribution among all the choices, slightly favoring the correct choice (choice A). The posttest showed that most students were able to correctly identify the definition of the term quantized, but the number of students choosing distractor B stayed roughly constant. This is probably due to the fact that Planck's equation was also covered, mathematically showing the conversion of the energy of light quanta to light frequency, confusing students to the true meaning of the equation.

Question Fourteen:

What is an orbital?

a. *The path of an electron* ***52 % | 49 % | 80 %***
b. A circular path **24 % |2 % |5 %**
c. Gravitational pull **3 % |0 % |0 %**
d. The configuration of the electron **11 % |12 % |2 %**
e. The energy level of an electron **10 % |37 % |13 %**

This stem probes the student's understanding of an atomic orbital. Orbitals are tough for students to grasp as they do not have a good understanding of geometry or probability at this age. Most students on the pre- and posttest were able to correctly identify that an orbital represents a region of space where an electron most likely exists (choice A), though. Distractor B, a circular path, and C, gravitational pull, address the misconception that electrons act as planets. These choices were popular on the pretest, but not very popular on the posttest. Distractor D, the configuration of the electron, suggests that the

student understands that orbitals are part of reporting electron configurations, but not that orbitals are independent of electron configurations. Distractor E, which states that it is the energy level of an electron, is a similar misconception, but that the student is confusing orbital and energy level. Students have a tough time understanding what quantum numbers refer to and commonly switch the definition of the different quantum numbers. After energy levels were discussed, this choice became more popular as a consequence.

Question Fifteen:

How are chemical bonds determined to be ionic or covalent?

a. Nothing **0 % | 0 % |0 %**
b. *Differences in electronegativites* ***37 % |93 % |85 %***
c. Ionic bonds gain electrons, covalent bonds lose electrons **35 % |1 % | 5 %**
d. Covalent bonds are between three or more atoms **6 % | 2 % |0 %**
e. Covalent bonds are higher in energy **22 % |5 % |10 %**

This stem addresses the student's understanding of ionic versus covalent bonds. Most students have been exposed to various definitions of ionic and covalent bonds and recognize that there is a difference between the two (distractor A). The most common definition is that in ionic bonds, electrons are "transferred" whereas in covalent bonds, electrons are "shared." This definition is sufficient in most cases, but it does not tell how a covalent or ionic bond can be determined. Differences in electronegativity serve as a good basis for determining whether or not a bond would be ionic or covalent (choice B). Distractor C, ionic bonds give electrons, covalent bonds lose electrons, is similar to the definition that most students use for these bonds. As a consequence, many students chose this distractor on the pretest. Distractor D, covalent bonds are between three or more atoms, and E, covalent bonds are higher in energy, are true in some specific cases, but not in general, which may have led students to select these distractors.

Question Sixteen:

Why would the bond angles of ammonia (NH_3) and methane (CH_4) be different?

a. They are bonded to a different number of hydrogen atoms **43 % | 32 % |24 %**
b. Ammonia is smaller **4 % |0 % |3 %**
c. *Ammonia has a lone pair* ***4 % |65 % |70 %***
d. N and C have different properties **34 % |3 % |3 %**
e. Ammonia is ionic whereas methane is covalent **16 % |0 % |0 %**

This stem addresses the student's ability to think in three dimensions and to create VSEPR models for different molecules. It also requires the student to understand that the lone pair of electrons in the ammonia molecule will occupy a hybrid orbital and that lone electron pair will influence the hybrid orbitals around the nitrogen atom more than a bonding pair of electrons (choice C). It is tough question for students not exposed to VSEPR theory to answer correctly, as shown by the pretest results. Distractor B, ammonia is smaller, and C, nitrogen and carbon have different properties, are correct, but do not fully address the issue of bond angles. These distractors proved to be popular choices on the pretest, but much less so on the posttest. Distractor E, ammonia is ionic whereas methane is covalent, shows that students understand ionic and covalently bound substances have different structures, but not an understanding of what makes a substance ionic or covalent. Distractor A, they are bonded to a different number of hydrogen atoms, focuses on the most obvious difference. An obtuse angle from one hydrogen to another, through the non-bonding electron pair on ammonia, would be different than the roughly 109.5° bond angles on the methane molecule, but it is not conventional for measuring bond angles to consider this angle. This choice also fails to mention the non-bonding electron pair of nitrogen which restrict the bond angles of the hydrogen atoms to around 107°, which makes it not the best choice.

Question Seventeen:

Why would the bond angles of nitrogen tribromide (NBr_3) and aluminum tribromide ($AlBr_3$) be different?

a. Aluminum fluoride is ionic, nitrogen tribromide is covalent **30 % |21 % |25 %**
b. Nitrogen and aluminum have different electronegativites **18 % |8 % |2 %**
c. Aluminum is a metal, nitrogen is a non-metal **11 % |2 % |5 %**

d. *Aluminum and nitrogen have different numbers of valence electrons* **35 % |68 % |66 %**
e. Aluminum is bigger than nitrogen **6 % | 1 % |2 %**

This is the second question dealing with three dimensional shapes. This stem is slightly flawed, though, as it deals with a substance, aluminum tribromide, that is debatably ionic or covalent. It also forms dimers, which would further restrict the bond angles. If one uses a strict difference in electronegativity to determine bond character, the difference (1.36) falls into the category of being polar covalent, as most sources would define bond characteristics. This is the lens that the question should be viewed under. In this case, the distractor A, aluminum tribromide is ionic and nitrogen tribromide is covalent, is not correct. Students most likely chose this distractor because aluminum is a metal and bromine is a non-metal. Many students remember the difference between ionic and covalent bonds as "an ionic bond exists between a metal and a non-metal and a covalent bond exists between two non-metals" (as opposed to looking up their electronegativities). If aluminum tribromide is viewed as ionic, it will have a different (crystal) structure than nitrogen tribromide, making it a popular choice. Distractor B, which states that nitrogen and aluminum have different electronegativities, suggests a false idea that electronegativity relates directly to bond angles. Distractor C, aluminum is a metal, nitrogen is a non-metal, again addresses the idea that aluminum tribromide is covalent and not ionic. The fact that aluminum has a larger atomic radius than nitrogen (distractor E) shows that the student does not understand that the lone electron pair on nitrogen will make a larger difference than the size of the central atom. This is shown through choice D, which states that aluminum and nitrogen have a different number of valence electrons; nitrogen will form a different three dimensional shape than aluminum tribromide because of the lone electron pair on nitrogen.

Question Eighteen:

What is meant by saying that a bond is polar?

a. *Electrons are being un-equally shared* **24 % |92 % | 92 %**
b. Electrons are being equally shared **11 % |6 % |3 %**

c. It is stable **17 % |0 % | 1 %**
d. It has a negative charge and a positive charge **22 % | 2 % | 3 %**
e. There is more than one electron being shared **26 % |0 % |0 %**

This stem tests a student's understanding of polarity. Bond and molecule polarity are two concepts that are frequently confused. Students struggle to see how a bond could be polar or non-polar and how this affects the molecule as a whole. As these students have not had a true previous chemistry course, few were able to correctly identify this concept on the pretest. Many confused the idea of polar bonds and ionic bonds. This led the student to select distractor D, it has a full negative and a full positive charge, more often. Confusing the terms polar and non-polar will lead to the selection of distractor B, electrons are being shared equally. Though more than one electron may be shared in a polar covalent bond, it does not define the bond as being polar, making distractor E incorrect. Distractor C, it is stable, shows that the student does not understand polarity or its relationship to molecule stability.

Question Nineteen:

What is meant by saying that a molecule is polar?

a. It is made of polar bonds **17 % | 8 % |11 %**
b. It has an electronegativity **0 % | 2 % | 3 %**
c. It has a magnetic field **53 % |2 % |1 %**
d. *The electrons are not evenly distributed throughout the molecule* ***17 % |82 % |77 %***
e. The electrons are evenly distributed throughout the molecule **13 % |6 % |8 %**

This is another question on polarity, this stem focusing on molecule polarity. Students have a difficulty visualizing molecules in three dimensions. In addition to that, visualizing how bonds on opposite sides of the central atom would have no overall force vector for the molecule as a whole (leading to a non-polar molecule). Distractor A, which states that it (the molecule) is made of polar bonds, addresses this misconception. Students incorrectly perceive that polar bonds alone will lead to a molecule being polar. None of the students tested had taken a physics course which would have introduced them to the concept of vectors. Many of them have also only taken basic trigonometry as well, which exacerbates this

problem and the student's inability to make sense of polar molecules. Being able to visualize in three dimensions without a given vector diagram is difficult for many students. Choosing distractor E, the electrons are evenly distributed throughout the molecule, shows that the student has confused molecule polarity with molecule non-polarity. Distractor C, it has a magnetic field, shows that the student is relating the polarity of the bond with the magnetic poles of the Earth, as all students have learned about the magnetic poles of the Earth at this point in their academic career. Though polar molecules would react to a magnetic field, this does not fully explain the concept. For distractor B, it has an electronegativity, the student is demonstrating that they know that electronegativity is related to polarity, but not in what capacity they are related.

Question Twenty:

When salt dissolves in water, what happens to the bonds between the sodium and chloride ions?

a. They are weakened and spread apart **17 % |17 % |13 %**
b. They melt **0 % |0 % |0 %**
c. *They break apart and bond with water* ***53 % | 30 % |45 %***
d. The intramolecular bonds stay together, but the intermolecular bonds break **17 % |33 % |26 %**
e. The intermolecular bonds stay together, but the intramolecular bonds break **13 % |20 % |16 %**

This stem is addressing misconceptions around dissolving ionic substances. Many students believe that the substances merely disappear or are covered up by the water molecules as they dissolve. As students better understand the process of dissolution, they realize that intermolecular bonds are part of the process. Distractors D, the intramolecular bonds stay together, but the intermolecular bonds break, and E, the intermolecular bonds stay together but the intramolecular bonds break, both address this issue. For distractor D, the student is confusing what would occur with a covalent substance dissolving and an ionic substance dissolving. The covalent substance would not break the intramolecular bonds, where an ionic substance would. Distractor E is a slight change of distractor D, except is shows that the student has confused intermolecular and intramolecular bonds. Distractor A, which states that they (bonds) are

weakened and spread apart, shows an understanding that the solute is spread out throughout the solvent, but not why or how this process occurs. Distractor B, they melt, was not chosen by any student on the posttest, as most students associate melting with high temperatures. Ironically through melting an ionic substance, the substance splits into ions, being similar to the dissolution process (without the solute-solvent bonding).

Question Twenty-One

For the same salt solution, how does the mass of the solution compare to the mass of the water alone? How does the volume compare?

a. *The mass increases, the volume stays roughly the same* ***50 % |58 % |67 %***
b. The mass stays roughly the same, the volume increases **10 % |5 % |4 %**
c. The mass and volume both increase **18 % |22 % |13 %**
d. The mass and volume both stay roughly the same **14 % |15 % |14 %**
e. The mass increases, but the volume decreases **9 % |1 % |2 %**

This stem deals with the dissolution process again but addresses the misconception that the solute is "gone" and therefore contributes nothing to the mass of the mixture. It also addresses the misconception that adding a solid into solution will increase the volume of the solution by the volume of the solid solute. Most students are able to discern that the volume will not decrease when volume of solvent alone is compared to solution (distractor E), but many think that the mass and volume both increase (distractor C). Though the volume will increase very slightly, it will only significantly increase if there is a large amount of solute added or if the solute is a hydrated salt. This misconception persisted from the pre- to the posttest. Choosing distractor D, the mass and volume both stay roughly the same, shows that the student incorrectly identifies that the solute has actually disappeared. Since the solute is "gone" it does not contribute to the mass or volume of the solution. Distractor B, the mass stays roughly the same, but the volume increases, was also an unpopular choice as most students realize that either the mass will increase or identify with distractor D.

Question Twenty-Two:

What causes substances to react with one another?

a. The neutrality of the substance **3 % | 2 % |4 %**
b. Electrons are shared **28 % | 11 % |27 %**
c. Attractions between electrons **21 % |23 % |16 %**
d. *Attractions between molecules* ***18 % |27 % |26 %***
e. Both c and d **29 % |38 % |27 %**

This question gets at the misconception that substances react in order to be neutral (distractor A, the neutrality of the substance) or that electrons are attracted to each other (distractor C). This was one of the most missed questions on the posttest both years that the test was given. This question was also commonly missed and highly debated by many of my colleagues who reviewed the exam. As one gains more knowledge in chemistry, it seems as though it is easy to lose track of the attractions between protons and electrons which lead to the formation of bonds and focus on orbital overlap or molecular orbital theory. The idea that a substance is (generally) mores stable if neutral is the idea that students hold in selecting distractor A. The problem with that distractor is that it implies that a substance reacts because it is neutral rather than to obtain the stability of becoming neutral. The definition of a covalent bond that many students have, of electrons being shared, has been confused with the driving force of the reaction for distractor B. Distractor C, which states attractions between electrons, as well as distractor B, demonstrates the misconception that it is attractions between two electrons that cause a bond. This also coincides with the covalent bond definition and the propensity of considering how much an atom "needs to fill its octet," that electrons would be attracted to one another. This was the distractor most selected by faculty as well. Distractor E, both choice C and D, suggests that the student understands that there are attractive forces between protons and electrons, but that they are not responsible (solely) for reactions, clinging on to the idea that electronic attractions drive reactions as well.

Question Twenty-Three

Why does a cup filled with water not spill out even when the water level is slightly above the rim?

a. *The surface tension of the water keeps it together* ***54 % |89 % |91 %***
b. Water has a sturdy center **1 % |0 % |0 %**
c. Water has a high friction with the cup **4 % |3 % |0 %**
d. The air resistance/pressure is stronger than the gravitational pull **10 % |2 % |5 %**
e. Water has a meniscus **31 % |6 % |3 %**

This stem deals with a scenario that many students have experienced in their day to day lives and have most likely formed a conclusion about before it was properly explained to them. In this scenario, the surface tension of the water keeps it from flowing over (choice A). Distractor D, which states that the air resistance/pressure is stronger than the gravitational pull, suggests that the student does not fully understand air pressure, but knows that it has an affect in other scenarios. Distractors B, water has a sturdy center, and C, water has high friction with the cup, were not popular choices. Some students equate the tendency of water to bead with it having a "sturdy center." Others realize that frictional forces will affect substances, but not how those frictional forces factor in to this scenario. Distractor E, which states that water has a meniscus, was the second most popular choice on the pretest. This stems from the fact that students have been told for years about water's meniscus in glass containers, but not why a meniscus forms. This suggests that students do not understand the term meniscus and relate it to any "bending" (i.e. refraction, surface tension) of water.

Question Twenty-Four:

Why does it take longer to boil an egg in Denver than at sea level?

a. The air is thinner, not allowing molecules to conduct heat as well **24 % |5 % |2 %**
b. High altitude itself causes eggs to boil longer **2 % |1 % |1 %**
c. Lower air pressure causes eggs to boil longer and water to not heat up as fast **16 % |9 % |16 %**
d. Water has a higher boiling point at higher altitudes, it takes longer to get there **40 % |23 % |22 %**
e. *Water has a lower boiling point at higher altitudes, the water isn't as hot* ***18 % |62 % |59 %***

This stem addresses misconceptions relating to atmospheric pressure and boiling point as well as heat and energy. Many students do not understand that altitude has a relationship to air pressure, or where

air pressure originates from in general. This also comes back to the issue of gases having mass and gases being able to influence other phenomena. Finally, it addresses the difference between a substance boiling and a substance being hot. As all students have experienced water boiling and know that boiling water is hot, they equate the term boiling with something being hot. When presented with the cases of substances boiling at or below room temperature, many students will tell one that the substance is evaporating, showing a disconnect between the terms boiling and evaporating. Therefore, as water boils at a lower temperature it is capable of heating up heat substances (eggs in this case) up faster. Students also hold the misconception that all boiling water is at the same temperature, leading to the belief that this statement is in fact not true. Distractor A, which states that the air is thinner, not allowing molecules to conduct heat as well is true and many students are familiar with this idea, but as the metal and water are conducting heat, it does not apply in this scenario. Distractor B, high altitude itself causes eggs to boil longer, suggests that the student does not understand the relationship between air pressure and altitude, but that the student has heard the saying that eggs take longer to boil at higher altitudes. Distractor C, which states that lower air pressure causes eggs to boil longer and water to not heat up as fast, suggests that the student does understand the relationship between air pressure and altitude, but holds the misconception that air pressure has a relationship to heating (rather than to vapor pressure). Distractor D, which states that water has a higher boiling point at higher altitudes, it takes longer to get there, shows that the student understands that boiling point is affected by altitude, but that the student has switched the relationship – where the boiling point has gone up with a lower atmospheric pressure.

Question Twenty-Five:

If a sample of water were compressed to a very high pressure, what would happen?

a. The molecules would come together, causing the water to freeze **18 % | 28 % |26 %**
b. *The molecules would come together and become more dense (but still water)* ***38 % |32 % |22 %***
c. The sample would explode **14 % | 5 % |5 %**
d. The sample would speed up and heat up, eventually boiling the water **17 % |18 % |43 %**
e. This is impossible **13 % |18 % | 4 %**

This stem deals with the density of water as a solid compared with water as a liquid. Most students can tell one that ice floats because it is less dense than water. Students also identify that substances will revert to their most condensed form when compressed. When presented with this scenario, though, there is an obvious disconnect between these ideas as few students answered this correctly on the pretest and even fewer on the posttest. Distractor A, the molecules would come together, causing the water to freeze, demonstrates this disconnect. The student is still under the false understanding that a compressed liquid will turn into a solid in all cases. Distractor C, which states that the sample would explode, suggests that the student has experienced compressed substances exploding, either personally or in media (e.g. balloons, compressed gases), but it does not apply to this scenario as they have rarely experienced a case where pressure was evenly applied in all dimensions. Distractor D, which states the sample would speed up and heat up, eventually boiling the water, shows that the student has an understanding between pressure and temperature, but not that the proportionality exists for gases and not liquids. This choice was selected much more often on the posttest rather than the pretest, owing to the fact that gas laws had been covered in depth and students were most likely applying Gay-Lussac's law of gases to this scenario. Distractor E, this is impossible, shows that the student understands that liquids are not very compressible, but not of the consequences of an extremely high pressure scenario.

Question Twenty-Six:

Under normal atmospheric conditions, is it possible for water to evaporate below its boiling point?

a. *Yes* ***38 % | 75 % | 60 %***
b. No **40 % | 15 % | 27 %**
c. Yes, in a closed container only **19 % | 11 % | 13 %**
d. No, in a closed container only **3 % | 0 % | 0 %**

This stem addresses understanding of Kinetic Molecular Theory as well as the definition of temperature as an average of particle speeds. All students have witnessed the evaporation of water out of a glass or off

of a towel, but when the question is asked in this fashion, most answer incorrectly. This suggests a misunderstanding that something can only boil if at its normal boiling point. Even on the posttest, a large percentage of students held on to the misconception that this is not possible, though they were given numerous examples of this in class. Distractors C and D refer to a closed container, testing students ability to understand when a closed container affects a system. When teaching gas laws, references are frequently made to reactions in a closed container, leading students to have the misunderstanding that gas laws (and gas behavior in general) only hold true in closed containers. While the exact proportionality does not hold true outside of a closed container, the qualitative trend is still usable. Interestingly, about the same number of students chose C, yes, in a closed container only, on the pre- and posttest, but the number choosing A went up significantly. This suggests that students do not know when a closed container affects a gaseous system on the posttest as well.

Question Twenty-Seven:

How does a water strider bug "walk" on water?

a. The oils in its feet repel the water **5 % |8 % |3 %**
b. It is less dense than the water, therefore it floats **26 % |10 % |6 %**
c. It distributes its weight very evenly **6 % |5 % |3 %**
d. It travels with very high momentum **6 % |3 % |0 %**
e. *It doesn't break the surface tension of the water* ***57 % | 75 % |87 %***

This stem is an attempt to address surface tension in a scenario that a student might have previously experienced or been taught about. The major misconception that students have is that the bug is less dense than the water so that it can float on the surface (distractor B). This comes from the knowledge that objects less dense than water will float, but the student confuses the ability to float with the inability to break the surface tension of the water (choice E). Distractor A, which states that oils in its feet repel water, suggests that the student knows that oil will float on the surface of water, but not that this fact does not fully explain the scenario. Distractor C, which states that it distributes its weight evenly,

suggests that the student knows that pressure is higher the less spread out an object's weight is, which does play a part in the bug's ability to stay above the surface but does not fully explain the phenomena. Distractor D, which states that it travels with very high momentum, suggests that the student believes that the bug strides on water similarly to how a stone would skip on the surface of water. Once the topic of surface tension is covered, though, most students are able to answer this question correctly even though the exact example is not necessarily covered in the course.

Question Twenty-Eight:

If you heat up an aluminum can with some water in it and then place the opening of the can to a sample of cold water, the can crushes. Why?

a. The pressure outside of the can builds up until it eventually crushes the can **14 % |15 % |5 %**
b. The heat change happens so fast, crushing the metal in the process **31 % |7 % |9 %**
c. The difference in density of the metal crushes the can **7 % |1 % |0 %**
d. *The gas condenses inside the can, taking the can with it* ***46 % |78 % |83 %***
e. Cold temperatures always make things shrink **2 % |0 % |3 %**

This is a common demonstration that many students have seen before and all have seen by the end of the course. Student misconceptions around this demonstration arise from the rapid temperature change. Many have experienced this with the example of glass breaking from thermal shock or metals expanding through thermal expansion, but few have realized that they have experienced this with respect to gases. Because the crushing of the metal is what the students see, many think the driving force for this demonstration relates to the can itself, not the gases present inside of the can (distractors B, C, and E). Distractor B specifically shows that the student knows that rapid temperature change can cause things to break, but not why the breaking or crushing happens. Distractor E suggests that the student knows that cold temperatures cause contraction of substances, but not that it relates to how the cold temperatures might cause the gases to condense (choice E). Distractor A suggests that the student understands that pressure is related to the phenomena, but not that it is the pressure inside the can is the driving force, not

the pressure outside of the can. This distractor was more popular once the students had spent some time learning about the gas laws.

Question Twenty-Nine:

If you put a helium balloon into a freezer, it shrinks. Why?

a. Gas escapes through the pores of the balloon **3 % |1 % | 4 %**
b. The gas condenses into a liquid, taking up less space **30 % |18 % |6 %**
c. The cold temperatures of the freezer cause the elasticity of the balloon to go down **24 % |10 % |14%**
d. There is a pressure difference inside the freezer **20 % |14 % |14 %**
e. *The gas lowers its volume inside the balloon* ***22 % | 58 % |61 %***

This stem is probing a student's understanding of Charles' Law and is something they might have been shown in previous years. This stem was difficult for most students, very few selected the correct answer on the pretest. The most common response was that the gas would condense to a liquid, distractor B. They have learned in previous years that liquids take up less space than gases and this logic suggests why they would choose distractor B. The gas escaping through the pores (distractor A) is also something that students have personally observed and most can properly identify the mechanism for the gas escaping (as shown through question 30). Students also demonstrate a good understanding that this process takes time and does not apply in this case as only a small group of students selected this answer. The shrinkage of the balloon being attributed to cold temperatures (distractor C) again addresses the misconception that cold temperatures cause everything (not just gases) to occupy a smaller volume. Distractor D, which states that there is a pressure difference in the freezer, was a popular choice on both the pre- and posttest. This shows that the student does understand that increased pressure would cause the balloon to shrink, but not that there is no real pressure differential between a freezer and outside of the freezer. The student also does not demonstrate the understanding that temperature is a factor in this case, either.

Question Thirty:

Why would a balloon shrink over time if left out?

a. *Gas escapes through the pores of the balloon* ***53 % |73 % |92 %***
b. The pressure outside of the balloon builds up **9 % |13 % | 3 %**
c. The balloon was obviously not tied properly **3 % | 2 % |2 %**
d. The gas loses energy over time and therefore volume **31 % |9 % |2 %**
e. Gas disintegrates over time **4 % |2 % |0 %**

This stem drives at the student's ability to understand the size of gas molecules and understand the effects of atmospheric conditions. Most students were able to properly identify that the gas effuses through the pores of the balloon (choice A), but many held the misunderstanding that there were environmental factors as well. Distractor B, which states that the balloon shrinks from a pressure buildup, again suggests an understanding that increased pressure would cause the shrinking of the balloon, but not how that pressure would have come about in normal atmospheric conditions. Distractor D, the gas in the balloon loses energy over time and therefore volume, returns to the idea that if something cools or loses energy it will naturally shrink. This choice also suggests that the student may be thinking about Charles' Law of gases as the reason to why the balloon is shrinking, but that would require a significant change in temperature. Distractors C and E suggest that the student does not understand why the balloon shrinks at all and is choosing a scenario where an outside force would cause the balloon to shrink.

Question Thirty-One:

If you have two identical balloons of hydrogen and oxygen gas, which has a larger volume? Number of moles? Mass?

a. Volume is the same, hydrogen has more moles, oxygen has more mass **40 % |53 % |48 %**
b. *Volume is the same, moles are the same, oxygen has more mass* ***29 % |42 % |33 %***
c. Oxygen has more volume, hydrogen has more moles, oxygen has more mass **18 % |2 % |11 %**
d. Volume is the same, moles are the same, mass is the same **8 % |3 % |3 %**
e. Hydrogen has more volume, hydrogen has more moles, hydrogen has more mass **5 % |1 % |4 %**

This stem addresses density of gases and the ideal gas law. Most all students realize that not all three will be the same for the two balloons (distractor D), but on both the pre- and posttest, students held the misconception that hydrogen, being a smaller molecule, will have more particles (distractor A). It is very

difficult for students to grasp the idea that given two equal volumes of gas at the same temperature and pressure, the samples could have the same number of particles constituting them. This suggests that students misunderstand that because hydrogen is a smaller molecule more hydrogen molecules will "fit" in the given volume, though they are taught through the ideal gas law to ignore the volume of each individual gas molecule when considering the volume of the gas as a whole. Distractor D, that oxygen has more volume, hydrogen more moles, and oxygen more mass, again demonstrates the misconception, along with the idea that because oxygen is a larger molecule, it should occupy a larger volume. Distractor E, which states that hydrogen is greater for all three measures, shows that the student has a very low understanding of the gas laws in general.

Question Thirty-Two:

In a sample of pure oxygen gas, what exists between the molecules? How does this compare to air?

a. *They both have empty space between them* ***12 % | 34 % |25 %***
b. Oxygen has empty space between the molecules but air has other molecules between its molecules. **43 % | 40 % |28 %**
c. Oxygen has intermolecular bonds between the molecules, but air has intramolecular bonds between molecules **31 % |16 % |34 %**
d. Oxygen has empty space between the molecules, but air has nitrogen between its molecules. **11 % | 9 % | 12 %**
e. Oxygen and air both have density between their molecules **4 % |1 % |1 %**

This stem addresses two misconceptions, that there has to be some particle or particles between gas molecules and the differences between pure substances and mixtures. Most students think that oxygen will have nothing but empty space between the molecules, but when a sample of air is considered, there are other particles between the molecules (distractor B). This misconception arises from a misunderstanding of mixtures and pure substances. Students also frequently chose distractor C, intermolecular bonds for oxygen but intramolecular bonds for air. This suggests a misunderstanding of the terms intermolecular and intramolecular, as well as the same misunderstanding that the scenario would be different for mixtures versus pure substances. Distractor D, which states that oxygen has empty

space, but air has nitrogen in-between molecules, suggests that the student is aware of the fact that nitrogen constitutes a large proportion of the atmosphere, but not that this does not apply to this scenario. Distractor E, oxygen and air both have density between their molecules, demonstrates a misunderstanding of the concept of density.

Question Thirty-Three:

People say heat rises. With respect to gases, what should they say?

a. Gases rise because they are hot **3 % |2 % |0 %**
b. *Hot gases rise because they are less dense than surrounding air* ***83 % |83 % |82 %***
c. Hot gases rise because they are more dense **2 % | 1 % |2 %**
d. Hot gases rise from high pressure to low pressure **7 % |11 % |11 %**
e. Hot gases travel faster and therefore rise **5 % |4 % |5 %**

This stem addresses the student's understanding of gas density and how it relates to temperature. Most students were able to identify that hot gases rise because they are less dense (choice B), but the percentage of students choosing the correct answer did not change from the pretest to the posttest. Interestingly, after gas laws were taught in class, the second most popular distractor became distractor D, which states that hot gases rise from high pressure to low pressure. This suggests that the student understands that gasses will diffuse from high pressure to low pressure, but they do not address the increased buoyant force from the decreased density. Distractor A, that gases rise because they are hot, demonstrates the misconception stated in the question, that heat (or hot objects) will rise. Distractor C, hot gases rise because they are more dense, suggests that the student has reversed his or her understanding of the relationship of the temperature of a gas sample to its density. Distractor E, hot gases travel faster and therefore rise, shows that the student understands that hot gases will travel faster, but that does not imply that they will travel faster in one direction only and will not cause the effect that this distractor suggests.

Question Thirty-Four

Why does a piece of metal feel colder than a piece of plastic when both are sitting at the same temperature?

a. *Metal is a good conductor of heat and plastic is a poor conductor of heat* ***35 % |55 % |46 %***
b. Metals always absorb energy **8 % |15 % |12 %**
c. Metals have stronger bonds than plastic **14 % |11 % |5 %**
d. Metals hold their heat better than plastic **6 % | 4 % |6 %**
e. A metal will lose more heat than a piece of plastic **38 % |15 % |30 %**

This stem addresses the topics of system versus surroundings and that of conduction. Students have a very hard time understanding the role of conduction in a qualitative sense. All students have touched something metal on a cold or hot day and have started to develop some understanding of why the metal feels particularly cold or hot. The results of the pretest suggest that students think that the piece of metal loses more heat than the piece of plastic, causing it to feel colder (distractor E). This idea shows that the student fails to recognize that the cold sensation is from heat transferring from the student's hand to the object rather than the object transferring heat to the student's hand. It is very difficult for students to understand that the sensation of "hot" or "cold" arises from heat transferring into or out of one's body and that the metal, as a better conductor, will transfer that heat at a faster rate (choice A). Distractors B and C may be true in specific cases that a student may be aware of, but are not true in all cases and do not fully explain this phenomena. Distractor D, metals hold their heat better than plastic, suggests that the student has reversed their understanding of specific heat, that the metal will most likely have a higher specific heat and hold more heat than the plastic material.

Question Thirty-Five:

When liquid water freezes, is this process exothermic or endothermic?

a. *Exothermic* ***46 % |79 % |62 %***
b. Endothermic **44 % |19 % |29 %**
c. Neither **10 % | 2 % |9 %**

This stem addresses the terms endothermic versus exothermic as well as the heat exchange associated with the phase change of freezing. The pretest shows the students are fairly split on this process being endothermic or exothermic. This misconception could arise from the student not fully understanding the terms (though they have been addressed in previous courses). Students were able to correctly answer this question on the posttest, but the misconception that the process is endothermic still persisted. Another misconception that students hold is that if something goes through a reaction at a temperature colder than room temperature, that reaction must be endothermic. Students learn through the course that endothermic reactions take in heat and would feel cold at room temperatures (and are shown examples of this) which could possibly give them the misunderstanding that because ice freezes below room temperature, it would be endothermic.

Question Thirty-Six:

If you were to touch an endothermic chemical reaction, it would feel ____ because ______ .

a. hot, energy is absorbed by your hand **20 % |5 % |4 %**
b. hot, energy is absorbed by the reaction **17 % | 7 % |4 %**
c. cold, energy is flowing into your hand **13 % |3 % |8 %**
d. *cold, energy is flowing into the reaction* ***39 % |85 % |83 %***
e. cold, energy can't flow (it isn't exerted) **12 % |1 % |1 %**

This stem addresses both endothermic and exothermic reactions as well as the concept of the system versus the surroundings. Students do not have much trouble memorizing definitions of terms like endothermic and exothermic, but applying these terms to specific scenarios is much more difficult for them as evidenced by the pretest. Distractor A, which states for the first blank hot and the second energy is absorbed by your hand, suggests that the student has a misconception on the perspective on how heat flows in this scenario. The student is under the false idea that heat is flowing out of his or her hand. This arises from the misunderstanding of the perspective of the reaction. Students will memorize that heat flows "in" for an endothermic reaction but in this scenario they are not realizing that the heat is flowing into the reaction vessel, rather than into their hand as they selected. Distractors B and C have one part of

the stem answered correctly, but the other part is incorrect, suggesting that the student has a partial understanding of heat flow and the term endothermic, but has some portion still confused. Distractor E, cold, energy can't flow, suggests that the student does not understand that heat could possibly flow in or out of one's hand and in the absence of that heat flow (or heat in general as students mentioned on their initial surveys), the reaction vessel would be cold.

Question Thirty-Seven

Is energy released or taken in when a chemical bond is broken?

a. It depends on the bond **15 % |19 % |14 %**
b. Released, heat flows out of the bond **19 % |19 % |26 %**
c. Released, the bond stored energy **60 % |30 % |28 %**
d. *Taken in, all bonds take energy to break* ***6 % |32 % |32 %***
e. Taken in, the bonds are weak **0 % |0 % | 0 %**

This stem represents a commonly held misconception of many students, that chemical bonds store energy. Much of this arises from the way that teachers describe chemical potential energy – as "stored" energy. Many teachers refer to chemical bonds as the stored potential energy from chemical reactions. Also, from student's own experiences where substances go through chemical reactions where energy is released (such as combustion reactions) reinforces this misconception that when substances break their bonds, energy is released. What the student (and sometimes the teacher) is failing to take into account is the difference between the bond energy of the products and the reactants, which represents the energy released through the reaction. Distractor C, which states released, the bond sored energy, represents this misconception and was the most common pretest choice as well as the most common distractor chosen on the posttest as well. Distractor B, released, heat flows out of the bond, suggests that the student understands that heat released and heat flowing out of the system are equivalent statements, but again the student has the misconception that chemical bonds release energy when they are broken. Distractor A, it depends on the bond, shows that the student does not realize that all bonds are fundamentally the

same attractive forces and would not be different from one another. Distractor E, which states taken in, the bonds are weak, was not selected on the pre- or posttest by any of the students.

Questions Thirty-Eight:

What is happening when we "salt" roads?

a. *The salt lowers the melting point of the ice/water* ***26 % |78 % |43 %***
b. The salt absorbs the salt/water **17 % |3 % |3 %**
c. The salt goes through an exothermic reaction, melting the ice **44 % |8 % |44 %**
d. The ice dissolves in the salt **5 % |0 % |3 %**
e. Salt does not allow water to bond into ice **9 % | 11 % |6 %**

This stem addresses the colligative property of freezing point depression in a scenario that students have observed in their everyday lives. The misconception that students most commonly display is that the salt melts the ice through some kind of exothermic reaction with the ice itself (distractor C). This most likely arises from the observation that the ice is no longer solid after the salt has been applied (and therefore melted) or the names of popular magnesium chloride products (like IceMelt®). Though the dissolution of these salts in water is slightly exothermic, in no way does this process produce enough heat to melt the ice. Distractor B, the salt absorbs the salt/water, suggests that the student holds the misconception that salt absorbs water as it "dries things out" (this is further discussed in question 39). Distractor D, which states that the ice dissolves the salt, is partially true (the water is actually dissolving the salt) but does not explain the reasoning behind "salting" roads. Distractor E, salt does not allow water to bond to ice, is also true (at temperatures warm enough for the freezing point depression to be effective), but again does not directly explain the phenomena.

Question Thirty-Nine:

What happens when you pour salt on to a freshwater slug?

a. The slug dies because it cannot have salt in its environment **2 % |2 % |4 %**
b. The slug dies, the salt absorbs all the water from the slug **59 % | 20 % |51 %**

c. The slug dies, it melts **2 % |0 % | 1 %**

d. The slug dies, water flows out of the slug to equalize concentrations ***9 % |74 % |13 %***

e. The slug dies, the salt causes a chemical reaction on the skin of the slug, burning it **28 % |3 % |31 %**

This somewhat morbid stem addresses the concept of osmotic pressure in a scenario that the student may have experienced personally or heard about through media. The most common misconception that students have with respect to this scenario is that the salt is absorbing water from the slug, desiccating it and causing its demise (distractor B). What the student fails to realize is that it is not the salt that absorbs the water, but the difference in osmotic pressure that is created from the salt water solution created on the surface of the slug, causing the freshwater inside of the slug to flow out through its cell walls (which act as a semipermeable membrane) and for the slug to die (through crenation, as evidenced by choice D). Students who have been in salt water or gotten salt on their hands have realized that afterward their hands feel dry, suggesting that the salt itself has dried out their hands and apply this personal experience to the scenario, as well. Both cases exemplify the misconception previously stated; the student does not understand the role of osmotic pressure in the scenario. Distractor A, the slug dies because it cannot have salt in its environment, suggests that the student has had experience with saltwater organisms and knows that they need a specifically balanced environment in order to survive, but the distractor does not specify why the salt cannot be present and therefore does not explain the scenario. Distractor C, the slug dies, it melts, was not chosen by many students at all on either the pre- or posttest. Distractor E, the slug dies, the salt causes a chemical reaction on the skin of the slug, burning it, suggests that the student has not experienced this scenario and also does not understand how the concept of osmotic pressure applies to the scenario. Interestingly, osmotic pressure was not discussed in much depth the second year the pre and posttests were given and the percentages of students selecting each choice on the pre- and posttest varied less than ten percent for each choice. In the first year that the pre- and posttests were given, osmotic pressure (and this scenario) were covered and the results are much better for selecting the correct answer, but the idea that salt absorbs water (distractor B) remains popular.

Question Forty:

When the oceans freeze, is the ice that forms salty?

a. The oceans cannot freeze **13% | 14% | 2%**
b. The ice is salty because if formed from salt water **21% | 22% | 14%**
c. The ice is not salty, salt is more dense than ice (and it sinks) **28% | 33% | 23%**
d. The ice is not salty, the temperatures are not cold enough for salt to freeze **18% | 14% | 19%**
e. *The ice is not salty, salt cannot fit in ice crystals* ***18% | 17% | 40%***

This is a stem that addresses two phenomena that students struggle with, that salt water can freeze and that when the salt water freezes the ice largely has no salt present in its crystal structure. A substantial number of students hold the idea that the oceans cannot freeze under normal atmospheric conditions, though they are familiar with the polar ice caps. Distractor A, the oceans cannot freeze, addresses this misconception. It is also partially addressed through distractor D, the ice is not salty, the temperatures are not cold enough for salt to freeze, because although this implies that there is ice in the oceans, it also implies that any ice in the ocean is not arising from salt water, but from some other source. This distractor also suggests that the student has some understanding of the colligative property of freezing point depression and is applying that knowledge in this case. Distractor B, the ice is salty because it formed from salt water, shows a very commonly held idea, that sea ice has a high salt content. As the student has most likely not had any experience with sea ice or salt water freezing, it is difficult for them to form a conclusion in this scenario. Distractor C, the ice is not salty, salt is denser than ice (and it sinks) was the most commonly chosen distractor. This most likely arises from the fact that students are aware that salt water is denser than fresh water and understand this to be a plausible definition of why sea ice would not be salty.

CHAPTER V

CONCLUSIONS

The posttest exam was informed and generated from student responses to open ended pretests in 2010. As the student responses were open ended and the students had the ability to put answers in their own words, the wording from the pretest to the posttest had to be changed to make an answer that was not only uniform but also logical in a multiple choice format. In some cases, the correct answer was also need to be added because no student fully explained the question to a significant degree. The correct responses on the posttest needed to be simplistic enough so as to not alert the student to the answer, but they also needed to fully explain the scenario in question. This caused some problems of ambiguity to arise in the initial posttest and some minor changes were made to the wording to make the answers more understandable for the students. This is still a problem with some of the questions, especially questions 7, 8, 16, and 17. Further development or rewording of those questions is needed.

The questions were categorized according to the aspects of chemistry to which they relate. The highest gains were in topics that were not addressed in previous courses: bonding, intermolecular forces, thermodynamics, and gas laws. Bonding questions showed a 44% gain, intermolecular forces a 33% gain, thermodynamics a 25% gain, and gas laws a 24% gain. Large gains were evident in questions pertaining to these areas because students did not have strong previous knowledge in these areas. Also, multiple laboratory experiments were performed in the areas of intermolecular forces, thermodynamics, and gas laws. Computer simulations were used to show bonding and atomic structure (a 19% gain), which also helped students to visualize the concepts. Reinforcing learning through multiple modes of education was very helpful in these areas. The lowest gains were in the particulate nature of matter (4%), reactions and reactivity (-2%), and solubility (9%). Many of these areas were covered extensively in the physical science

course the previous year and gains predictably stayed flat. In the case of reactions, question twenty-two (the reason substances react with one another) remained a challenging question for both students and faculty. This topic was not stressed explicitly in the course, and future students would certainly benefit from a more thorough explanation of the topic.

This study suggests that through teaching directly and indirectly to student misconceptions, these misconceptions can be at least partially dislodged. Cases where visual, auditory, and tactile examples were used showed the most gains. Further materials should be developed to help in this process. Computer simulations were developed to demonstrate electron density in order to help with the concept of polarity. Two classes were exposed to these simulations, while the other two were given traditional ball and stick model kits. The data should be analyzed to determine the effectiveness of these simulations. Questions and topics that were discussed briefly or not at all in previous courses were omitted from the test as it was designed for first year chemistry students with minimal formal chemistry education. Further tests should be designed to examine second year chemistry students to see which misconceptions persist from first to second year. A wider study testing students years after the completion of the course would also provide useful insight as to whether misconceptions will return and if so, which misconceptions resurface as students distance themselves from the subject material.

APPENDIX

2011 Pre- and Posttest

Chemistry Post-Test

For all answers, choose the **most correct** answer

1. If you had a copper penny, how many atoms of copper would there be?
    a. Many
    b. One atom
    c. It depends on the mass of the penny
    d. It depends on the volume of the penny
    e. Twenty-nine

2. If you have a sample of salt water and you heat it in a **closed container** until all the water has evaporated, what is present in the container and how will the mass have changed?
    a. Salt alone, mass stays the same
    b. Salt and water vapor, mass stays the same
    c. Salt alone, mass decreases because there is no water
    d. Salt and water vapor, mass decreases because gas is less dense than water (liquid)
    e. Salt, hydrogen, and oxygen gas present, mass goes through a small change

3. During the process of evaporation, what is happening to the molecules of a liquid?
    a. Molecular bonds are breaking
    b. Molecules vibrate faster
    c. Liquid rises
    d. Intermolecular bonds are breaking
    e. Liquid decreases

4. If you were to take a sample of pure gold, dissolve it through a number of chemical reactions, and end up with a sample of only gold atoms, would this be a pure or impure sample of matter?
    a. Pure
    b. Impure
    c. Can't tell

5. Individual atoms can exist in either the solid, liquid, or gas phases
    a. True
    b. False

6. Will one gram of hydrogen gas and one gram of chlorine gas react completely? Use the following balanced equation:

$$H_2 + Cl_2 \rightarrow 2\ HCl$$

    a. No, because hydrogen and chlorine have different atomic masses
    b. No, because the reaction is balanced 1:1
    c. Yes, because the reaction is balanced 1:1
    d. Yes, because they will
    e. Yes, because they balance to two

7. If you had a bottle containing one molecule of hydrogen gas and one molecule of chlorine gas, would they react to make two molecules of hydrochloric acid gas?
    a. Yes, because that follows the balanced equation (they are 1:1)
    b. No, it will only make one molecule of hydrochloric acid gas
    c. No, the likelihood of the two particles colliding is too small
    d. Yes, they have similar charges
    e. Yes, but only if the pressure of the bottle were the same throughout

8. If you had less than one mole of hydrogen gas and less than one mole of chlorine gas in a container, would they react to make hydrochloric acid gas?
    a. Yes, because that follows the balanced equation (they are 1:1)
    b. No, you need a full mole for them to react
    c. No, because they are not at a 1:1 ratio
    d. Yes, the specific amount doesn't matter (assuming there are more than 0 molecules)
    e. Yes, if the amounts are equally less than one mole

9. You measure a box of matches to have a mass of 500 g. You then strike all the matches and put the ashes back in the box. You find the mass to be 490 g. Where did the 10 g of mass go?
    a. The mass was converted to energy (from the chemical reaction)
    b. The mass was converted to carbon dioxide
    c. The mass was lost to the reaction
    d. The mass was converted to carbon
    e. This is not possible, mass is conserved through chemical reactions

10. If you measure the mass of an iron bar to be 10.0 grams on a balance and then allow the bar to rust, will the mass go up, down, or stay the same as the bar rusts?
    a. The mass will go up from the added oxygen
    b. The mass will stay the same, there are no overall changes to the chemical formula
    c. The mass will stay the same, the law of conservation of mass applies
    d. The mass will go down, rust corrodes metal
    e. The mass will go up, rust is heavier than iron

11. Between the nucleus and the electrons in an atom, there is/are:
    a. Bonds
    b. Plasma
    c. Gas
    d. Protons and neutrons
    e. Empty space

12. What was wrong with Bohr's model?
    a. Nothing
    b. It was two dimensional
    c. There weren't any electrons
    d. It wasn't very accurate
    e. Electrons do not have fixed paths

13. What does it mean for energy to be quantized?
    a. It is defined by quantities or packets of energy
    b. It is measured in terms of light waves
    c. The light waves have been converted to mass
    d. Energy is being transferred
    e. Energy is contained

14. What is an orbital?
    a. The path of an electron
    b. A circular path
    c. Gravitational pull
    d. The configuration of the electron
    e. The energy level of an electron

15. What makes some chemical bonds ionic and others covalent?
    a. Nothing
    b. Differences in electronegativites
    c. Ionic bonds gain electrons, covalent bonds lose electrons
    d. Covalent bonds are between three or more atoms
    e. Covalent bonds are higher in energy

16. Why would the bond angles of ammonia (NH_3) and methane (CH_4) be different?
    a. They are bonded to a different number of hydrogen atoms
    b. Ammonia is smaller
    c. Ammonia has a lone pair
    d. N and C have different properties
    e. Ammonia is ionic whereas methane is covalent

17. Why would the bond angles of nitrogen trifluoride (NF_3) and aluminum fluoride (AlF_3) be different?
    a. Aluminum fluoride is ionic, nitrogen trifluoride is covalent
    b. Nitrogen and aluminum have different electronegativites
    c. Aluminum is a metal, nitrogen is a non-metal
    d. Aluminum and nitrogen have different numbers of valence electrons
    e. Aluminum is bigger than nitrogen

18. What is meant by saying that a bond is polar?
    a. Electrons are being un-equally shared
    b. Electrons are being equally shared
    c. It is stable
    d. It has a negative charge and a positive charge
    e. There is more than one electron being shared

19. What is meant by saying that a molecule is polar?
    a. It is made of polar bonds
    b. It has an electronegativity
    c. It has a magnetic field
    d. The electrons are not evenly distributed throughout the molecule
    e. The electrons are evenly distributed throughout the molecule

20. When salt dissolves in water, what happens to the bonds between the sodium and chloride ions?
    a. They are weakened and spread apart
    b. They melt
    c. They break apart and bond with water
    d. The intramolecular bonds stay together, but the intermolecular bonds break
    e. The intermolecular bonds stay together, but the intramolecular bonds break

21. For the same salt solution, how does the mass of the solution compare to the mass of the water alone? How does the volume compare?
    a. The mass increases, the volume stays roughly the same
    b. The mass stays roughly the same, the volume increases
    c. The mass and volume both increase
    d. The mass and volume both stay roughly the same
    e. The mass increases, but the volume decreases

22. What causes substances to react with one another?
    a. The neutrality of the substance
    b. Electrons are shared
    c. Attractions between electrons
    d. Attractions between molecules
    e. Both c and d

23. Why does a cup filled with water not spill out even when the water level is slightly above the rim?
    a. The surface tension of the water keeps it together
    b. Water has a sturdy center
    c. Water has a high friction with the cup
    d. The air resistance/pressure is stronger than the gravitational pull
    e. Water has a meniscus

24. Why does it take longer to boil an egg in Denver than at sea level?
    a. The air is thinner, not allowing molecules to conduct heat as well
    b. High altitude itself causes eggs to boil longer
    c. Lower air pressure causes eggs to boil longer and water to not heat up as fast
    d. Water has a higher boiling point at higher altitudes, it takes longer to get there
    e. Water has a lower boiling point at higher altitudes, the water isn't as hot

25. If a sample of water were compressed to a very high pressure, what would happen?
    a. The molecules would come together, causing the water to freeze
    b. The molecules would come together and become more dense (but still water)
    c. The sample would explode
    d. The sample would speed up and heat up, eventually boiling the water
    e. This is impossible

26. Under normal atmospheric conditions, is it possible for water to evaporate below its boiling point?
    a. Yes
    b. No
    c. Yes, in a closed container only
    d. No, in a closed container only

27. How does a water skimmer bug "walk" on water?
    a. The oils in its feet repel the water
    b. It is less dense than the water, therefore it floats
    c. It distributes its weight very evenly
    d. It travels with very high momentum
    e. It doesn't break the surface tension of the water

28. If you heat up a can with some water in it and then place the opening of the can to a sample of cold water, the can crushes. Why?
    a. The pressure outside of the can builds up until it eventually crushes the can
    b. The heat change happens so fast, crushing the metal in the process
    c. The difference in density of the metal crushes the can
    d. The gas condenses inside the can, taking the can with it
    e. Cold temperatures always make things shrink

29. If you put a balloon into a freezer, it shrinks. Why?
    a. Gas escapes through the pores of the balloon
    b. The gas condenses into a liquid, taking up less space
    c. The cold temperatures of the freezer cause the elasticity of the balloon to go down
    d. There is a pressure difference inside the freezer
    e. The gas lowers its volume inside the balloon

30. Why will a balloon shrink if left out over time?
    a. Gas escapes through the pores of the balloon
    b. The pressure outside of the balloon builds up
    c. The balloon was obviously not tied properly
    d. The gas loses energy over time and therefore volume
    e. Gas disintegrates over time

31. If you have two identical balloons of hydrogen and oxygen gas, which has a larger volume? Number of moles? Mass?
    a. Volume is the same, hydrogen has more moles, oxygen has more mass
    b. Volume is the same, moles are the same, oxygen has more mass
    c. Oxygen has more volume, hydrogen has more moles, oxygen has more mass
    d. Volume is the same, moles are the same, mass is the same
    e. Hydrogen has more volume, hydrogen has more moles, hydrogen has more mass

32. In a sample of pure oxygen, what exists between the molecules? How does this compare to air?
    a. They both have empty space between them
    b. Oxygen has empty space between the molecules but air has other molecules between its molecules.
    c. Oxygen has intermolecular bonds between the molecules, but air has intramolecular bonds between molecules
    d. Oxygen has empty space between the molecules, but air has nitrogen between its molecules.
    e. Oxygen and air both have density between their molecules

33. People say heat rises. With respect to gases, what should they say?
    a. Gases rise because they are hot
    b. Hot gases rise because they are less dense than surrounding air
    c. Hot gases rise because they are more dense
    d. Hot gases rise from high pressure to low pressure
    e. Hot gases travel faster and therefore rise

34. Why does a piece of metal feel colder than a piece of plastic when both are sitting at the same temperature?
    a. Metal is a good conductor of heat and plastic is a poor conductor of heat
    b. Metals always absorb energy
    c. Metals have stronger bonds than plastic
    d. Metals hold their heat better than plastic
    e. A metal will lose more heat than a piece of plastic

35. When liquid water freezes, is this process exothermic or endothermic?
    a. Exothermic
    b. Endothermic
    c. Neither

36. If you were to touch an endothermic chemical reaction, it would feel _______ because ________.
    a. hot, energy is absorbed by your hand
    b. hot, energy is absorbed by the reaction
    c. cold, energy is flowing into your hand
    d. cold, energy is flowing into the reaction
    e. cold, energy can't flow (it isn't exerted)

37. Is energy released or taken in when a chemical bond is broken?
    a. It depends on the bond
    b. Released, heat flows out of the bond
    c. Released, the bond stored energy
    d. Taken in, all bonds take energy to break
    e. Taken in, the bonds are weak

38. What is happening when we "salt" roads?
    a. The salt lowers the melting point of the ice/water
    b. The salt absorbs the salt/water
    c. The salt goes through an exothermic reaction, melting the ice
    d. The ice dissolves in the salt
    e. Salt does not allow water to bond into ice

39. What happens when you pour salt on to a freshwater slug?
    a. The slug dies because it cannot have salt in its environment
    b. The slug dies, the salt absorbs all the water from the slug
    c. The slug dies, it melts
    d. The slug dies, water flows out of the slug to equalize concentrations
    e. The slug dies, the salt causes a chemical reaction on the skin of the slug, burning it

40. When the oceans freeze, is the ice that forms salty?
    a. The oceans cannot freeze
    b. The ice is salty because if formed from salt water
    c. The ice is not salty, salt is more dense than ice (and it sinks)
    d. The ice is not salty, the temperatures are not cold enough for salt to freeze
    e. The ice is not salty, salt cannot fit in ice crystals

2011 Posttest Answer Sheet

Chemistry Post-Test Answer Sheet

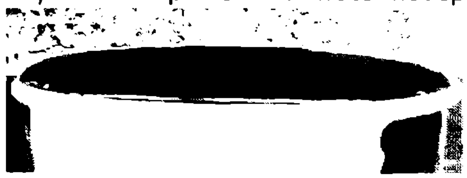
Name____________________

1. ______	16. ______	31. ______
2. ______	17. ______	32. ______
3. ______	18. ______	33. ______
4. ______	19. ______	34. ______
5. ______	20. ______	35. ______
6. ______	21. ______	36. ______
7. ______	22. ______	37. ______
8. ______	23. ______	38. ______
9. ______	24. ______	39. ______
10. ______	25. ______	40. ______
11. ______	26. ______	
12. ______	27. ______	
13. ______	28. ______	
14. ______	29. ______	
15. ______	30. ______	

Intermolecular Forces

Period_______

1. Why does a cup filled with water not spill even when the water is slightly over the brim?

Ex: 

2. Why does it take longer to boil an egg in Denver than at sea level?

3. What would happen if you took a sample of water and compressed it to very high pressure? What is happening to the molecules?

4. Why does water in an open cup slowly "disappear" over time?

5. How does a water skimmer bug "walk" on water? What would happen if you added some soap to the water?

Atomic Structure Pretest

Period_______

1. What exists between nuclei and electrons within an atom?

2. What does it mean to have properties of a wave?

3. What is wrong with Bohr's model?

4. What does it mean for energy to be quantized?

5. What is an orbital?

6. How does probability factor in to the description of the atom?

Atoms and Molecules Pretest

1. Why does a stone dropped into a glass of water sink to the bottom?
   a. The surface area of the marble is not large enough to be held up by the surface tension of the water
   b. The mass of the marble is greater than that of the water
   c. The marble weighs more than an equivalent volume of the water
   d. The force from dropping the marble breaks the surface tension of the water
   e. The marble has a greater mass and volume than the water

   Defend your choice:

2. If you have a beaker of salt where the salt has a mass of 100.0 g and a beaker of water where the water has a mass of 50.0 grams, what will be the mass of the mixture? Why?

3. What will be true of the volume of the resulting mixture? Why?

4. When a beaker of water boils, what is inside the bubbles?

5. True or False: An atom can be seen with an optical microscope.
   Defend your answer!

Stoichiometry Pretest

1. Will one gram of hydrogen gas react with one gram of chlorine gas completely? Use the following balanced equation:

$$H_2 + Cl_2 \rightarrow 2\ HCl$$

2. If you had a soda bottle at your house with one molecule of hydrogen gas and one molecule of chlorine gas, would they react to make two molecules of hydrogen chloride (hydrochloric acid) gas? Explain.

3. If you have less than one mole of hydrogen and less than one mole of chlorine gas, will a reaction occur between them to make hydrogen chloride gas? Why?

4. You measure a box of matches to be 500 g. You then strike all the matches and put the ashes back in the box. You find the mass to be 400 g. Where did the 100 g of mass go? How do you know?

5. If you measure the mass of an iron bar to be 10.0 g on a balance and then allow the bar to rust, will the mass go up, down or stay the same as the bar rusts? Explain.

Gas Laws Pretest

1. If you heat a can with some water in it and then put that over some cold water, the can crushes, why?

2. When you put a balloon in a freezer, it shrinks. Why?

3. Why does a balloon shrink over time?

4. How does a snow-maker work?

5. If you have two balloons of the same size, one of hydrogen and one of oxygen, which has more volume? Which has more moles of gas? Which has more grams of gas?

6. What exists between gas particles in a sample of pure oxygen? How does this differ from ambient air (like the air in this room)?

7. People say that heat rises. With respect to gases, what should they be saying and why?

Solutions and Solubility Pretest

1. When salt dissolves in water, what happens to the bonds between the sodium and the chloride ions? Why?

2. What would happen to the mass of the resulting solution compared to the original water mass? What about volume (before and after)?

3. Why do two substances react with one another when placed together?

4. What helps this reaction to occur?

5. Would any two substances react with one another? Explain.

Thermodynamics Pretest

1. Why does a piece of metal feel colder than a piece of plastic when both are sitting at the same temperature?

2. When water (liquid) freezes, is this endothermic or exothermic (energy flowing in or energy flowing out)?

3. If you were to touch an endothermic process (energy flowing in), would it feel cold or warm to the touch? Why?

4. When you strike a match to light a fire, is energy lost or gained? Explain.

5. Is energy released or taken in to break a chemical bond? How do you know?

Principal Approval Form

Cherry Creek High School
9300 E. Union Ave.
Greenwood Village, CO 80111
(720) 554-2285

Cherry Creek
Schools
Dedicated to Excellence

December 2, 2009

To Whom It May Concern:

I, Ryan Silva, acknowledge that Ethan Dusto, in conjunction with the University of Colorado Denver Campus, will be conducting research into the misconceptions that students have in the field of chemistry. The research will be conducted on the Cherry Creek High School campus. As the research is anonymous, voluntary, and follows general educational practice, it does not constitute any significant risk to the students involved. As this project is ongoing, it will potentially last for more than one semester and involve a second set of students, but students will not be tracked after they have graduated chemistry.

Sincerely,

Ryan Silva
Principal
Cherry Creek High School

School Board Research Request and Approval Forms

CHERRY CREEK SCHOOLS
Office of Assessment and Evaluation
Research Request

1.) Principle Investigator Information:

Name: Ethan Dusto ***Date:*** 9/1/09

Address: 8861 E. Amherst Dr. #B Denver, CO 80231

Phone/fax/email: 215-380-8214

Institution: University of Colorado Denver Campus

Study Supervised by: Doris Kimbrough

Title of Research Request: Identifying Common Misconceptions Among High School Chemistry Students

2.) Please submit a short abstract that describes the goals of the project, copies of your parent and student (if applicable) participation consent forms, and copies of your measures or questionnaires.

3.) Please complete the following information:

A.	**Specifically, what data do you need?**	Pretest data from first year chemistry students
B.	**How do you plan to collect your data? Explain.**	Pre and post tests given throughout the year
C.	**Will you administer surveys/questionnaires (if YES, attach 1 copy)?**	***Yes*** ***No***
D.	**Identify any data that you need to collect from existing District records.**	None
E.	**How much total time is required of students for participation?**	100 minutes
F.	**How much class time is required of students for participation (including prep time)?**	100 minutes
G.	**How much total time is required of teachers or other school staff for participation?**	N/A
H.	**How many subjects will be involved?**	***Students:*** 150 ***Teachers:*** 1 ***Parents:*** 0
I.	**When do you propose to collect data?**	Using pretests that I already give.
J.	**Have you discussed the proposed research with any school or district staff?**	***Names:*** Taylor Duffield, Ryan Silva
K.	**How will results of the research help the Cherry Creek School district?**	Potentially increasing misconception identification and information retention
L.	**Do you have approval from your institutional research review committee (attach 1 copy)?**	***Yes*** **In Process** ***No*** *(If no, include statement why none required)*
M.	**When will your completed research report be sent to our office and to participating schools?**	December 2010

CHERRY CREEK SCHOOLS
Office of Assessment and Evaluation
District Priorities & Objectives

Please check all that apply.

My research DIRECTLY relates to the following Cherry Creek Schools priorities or student achievement objectives:

Check All That Apply	District Student Achievement Objectives
	1. All students will meet or exceed district proficiencies and state standards. The percentage of students reaching *Proficient* and *Advanced* levels will increase yearly.
✓	2. All students will demonstrate yearly achievement growth.
	3. Minority students will meet or exceed district proficiencies and state standards and demonstrate yearly achievement growth.
	4. All students will read at grade level by the end of first grade.
✓	5. Students new to the district will be evaluated upon entry, and those working substantially below grade level will receive assistance to meet required proficiencies and standards and to demonstrate achievement growth.
	6. High performing students will receive an academic challenge commensurate with their abilities and demonstrate achievement growth.
	Colorado Basic Literacy Act
	1. By the end of third grade, students will be fluent readers will a full range of reading strategies to apply to reading a wide variety of increasingly difficult narrative and expository text.
	District In Search of Excellence Objectives
✓	1. Keep the pursuit of excellence the number one priority, coupled with a district commitment to continuous improvement.
✓	2. Hold high expectations for every student and actively assist each one to reach high academic standards irrespective of gender, race, or economic status.
	3. Emphasize the importance of participation in the academic core for all students whether they are planning on college or on immediate entry into a career after high school.
	4. Establish *Proficient* as the target achievement level for all students in reading, writing, and mathematics.
	5. Academically challenge and accelerate students to the greatest extent of their ability, interest, and motivation.
	6. Maintain excellence in the "enhanced core," and extracurricular programs in a manner that supports and complements high academic achievement and well-rounded students.
✓	7. Marshall the resources needed to deliver academic excellence and fulfill the district mission.
	8. Utilize leadership and governance structures that stress student achievement, accountability, collaboration, and stewardship.
	9. Use site-based decision making in tandem with a clear district focus to enhance student achievement and organization al efficiency.
	10. Build connectedness, trust, and confidence within the organization and community.
	11. Strengthen teacher and Administrator recruitment and development while increasing the diversity of the staff.
	12. Create an environment of physical and psychological safety at all schools and develop processes for identifying and helping troubled children.

CHERRY CREEK SCHOOLS
Office of Assessment and Evaluation

Research Agreement & Understanding

Please read the following agreement and sign.

I understand that approval of my research by the Office of Assessment and Evaluation does not mean:

- ✓ Official endorsement from the Assessment & Evaluation (A&E) office or the District.
- ✓ Assistance from A&E staff in securing or recruiting schools/participants for the study, or provision of data or data files needed to complete the study.

I understand that approval of research carries with it several responsibilities for me. I understand that:

- ✓ I must keep all records confidential.
- ✓ I must respect the rights and privacy of any schools and individuals concerned.
- ✓ I must not commence any part of the research activity in the district prior to obtaining District Approval for the study.
- ✓ I must contact the Cherry Creek Schools staff person or persons indicated on the District Approval letter, explain the study, and obtain their approval before any part of the research commences at their school or facility or with their students/staff.
- ✓ Cherry Creek's principals, teachers, students, and staff can decide to not participate in the research for any reason, and can revoke participation at any time.
- ✓ I must receive written permission by parents/guardians for their student's participation or release of individual student records.
- ✓ I must provide A&E and the participating school with one copy of a written report summarizing the study and results upon completion of the research.
- ✓ I must allow parents/guardians to inspect actual surveys and instructional materials used in the research study.

Submission of this application does not mean automatic District approval. The District can require that the applicant modify procedures, instruments, etc. in order for District Approval to be granted. The research approval process may take 2-3 months. Please submit your request well in advance of when you need to collect your data.

Signature: Ethan Duste Date: 9/1/09

Print Name: Ethan Duste

Please return by email if you have an electronic signature (or FAX) all three completed pages to:
FAX (720) 554-4488

Office of Assessment and Evaluation
Cherry Creek Schools
4700 S. Yosemite Street
Greenwood Village, CO 80111

September 3, 2009

To Whom It May Concern:

The research that I am conducting is in the area of science education. I am investigating misconceptions regarding chemistry students have developed throughout their lives that have not yet been dislodged. The goal of this research is to develop a standardized exam that can effectively identify these misconceptions for the teacher to then address.

All the research will be conducted using pre- and post-tests to see which misconceptions are present before instruction and which misconceptions are dislodged after instruction. All the testing surveys will be anonymous, and participation will be voluntary. Students and students' parents will be notified of the survey and how its results will be used. They will have to sign a waiver allowing the results to be used in the study before the research commences. The population being tested will be Cherry Creek High School chemistry and physical science students. The test answers will be used to generate an exam that can be used by teachers, and it will be provided to any teachers taking the time to allow their students to participate in the survey.

Thank you for considering this study for validity, and I hope to hear back from you soon.

Sincerely,

Ethan Dusto

SUBJECT: Approval of Research: "Identifying Common Misconceptions among High School Chemistry Students"

Dear Mr. Dusto:

Your request to do research in Cherry Creek Schools is conditionally approved, pending receipt of approval from your institution's IRB. Please forward a copy of this approval to our office once you receive it from The University of Colorado at Denver. Approval means that your research study complies with accepted research practices, procedures, and guidelines. Please understand that while our office provides a review of research requests, this approval does not mean participation in the study is required from District staff. Principals and staff can decide to participate or not in any district-approved research study.

Research is an integral part of our understanding of student learning and provides a foundation for our efforts to improve student knowledge and skills. However, teachers and principals are responsible for student attainment of an ever-growing number of state and district learning standards. Research that directly addresses the District's Student Achievement Objectives or other state, district, or school goals is viewed as a valuable use of principal, teacher, or student time, and is given priority over projects that do not address District or school goals.

I understand from your research request and other communications that the only district school involved in your study is Cherry Creek High School (CCHS). Final agreements and arrangements for participation

should be made through the CCHS principal, Mr. Ryan Silva.

Please call me if you have any questions related to this approval, and best of luck in completing your research project.

Sincerely,

M. Kevin Matter (signature)

M. Kevin Matter, Ph.D.
Director, Assessment & Evaluation

pc: Mr. Ryan Silva

Dr. M. Kevin Matter
Director, Assessment & Evaluation
Cherry Creek Schools
4700 S. Yosemite St.
Greenwood Village, CO 80111

720-554-4244
FAX 720-554-4488

email: kmatter@cherrycreekschools.org

IRB Approval Form

Colorado Multiple Institutional Review Board
13001 E. 17th Place
Building [illegible] Room [illegible]
Aurora, Colorado [illegible]

Mailing Address:
Mail Stop F-490
P.O. Box 6508
Aurora, CO 80045-6508

303-724-1055 (Phone)
303-724-[illegible] (Fax)
uchsc.edu/comirb (Web)
comirb@ucdenver.edu (E-Mail)
FWA[illegible] (FWA)

University of Colorado Hospital
Denver Health Medical Center
Veteran's Administration Medical Center
The Children's Hospital
University of Colorado Denver
Colorado Prevention Center

Certificate of Approval

25-Jan-2010

Investigator:	Ethan Dusto
Sponsor(s):	
Subject:	COMIRB Protocol 09-0592 Initial Application
Effective Date:	22-Jan-2010
Expiration Date:	21-Jan-2011
Expedited Category:	7
Title:	Determination and Mitigation of Misconceptions Among High School Chemistry Students

All COMIRB Approved Investigators must comply with the following:

- For the duration of your protocol, any change in the experimental design/consent and/or assent form must be approved by the COMIRB before implementation of the changes
- Use only a copy of the COMIRB signed and dated Consent and/or Assent Form. The investigator bears the responsibility for obtaining from all subjects "Informed Consent" as approved by the COMIRB. The COMIRB REQUIRES that the subject be given a copy of the consent and/or assent form. Consent and/or assent forms must include the name and telephone number of the investigator.
- Provide non-English speaking subjects with a certified translation of the approved Consent and/or Assent Form in the subject's first language.
- The investigator also bears the responsibility for informing the COMIRB immediately of any Unanticipated Problems that are unexpected and related to the study in accordance with COMIRB Policy and Procedures
- Obtain COMIRB approval for all advertisements, questionnaires and surveys before use.
- Federal regulations require a Continuing Review to renew approval of this project within a 12-month period from the last approval date unless otherwise indicated in the review cycle listed below. If you have a restricted/high risk protocol, specific details will be outlined in this letter. Non-compliance with Continuing Review will result in the termination of this study

You will be sent a Continuing Review reminder 75 days prior to the expiration date. Any questions regarding this COMIRB action can be referred to the Coordinator at 303-724-1055 or UCHSC Box F-490.

Review Comments:

Approval Includes:
Application for Protocol Review, ver. 01/12/10
Attachment A - Multi-Site
Attachment F - Expedited Review
Attachment H - Research Involving Children
Attachment T - Research in Public Schools
Protocol
Consent
Recruitment Script
7 Surveys

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